



STUDIES

— IN —

Stream Improvement



1. Progress in Lake and Stream Improvement.
2. Lake and Stream Improvement in Michigan.
3. Experimental Evidence on the Value of Trout Stream Improvement in Michigan.
4. An Evaluation of the Methods and Results of Stream Improvement in the Southwest.

by

Clarence M. Tarzwell

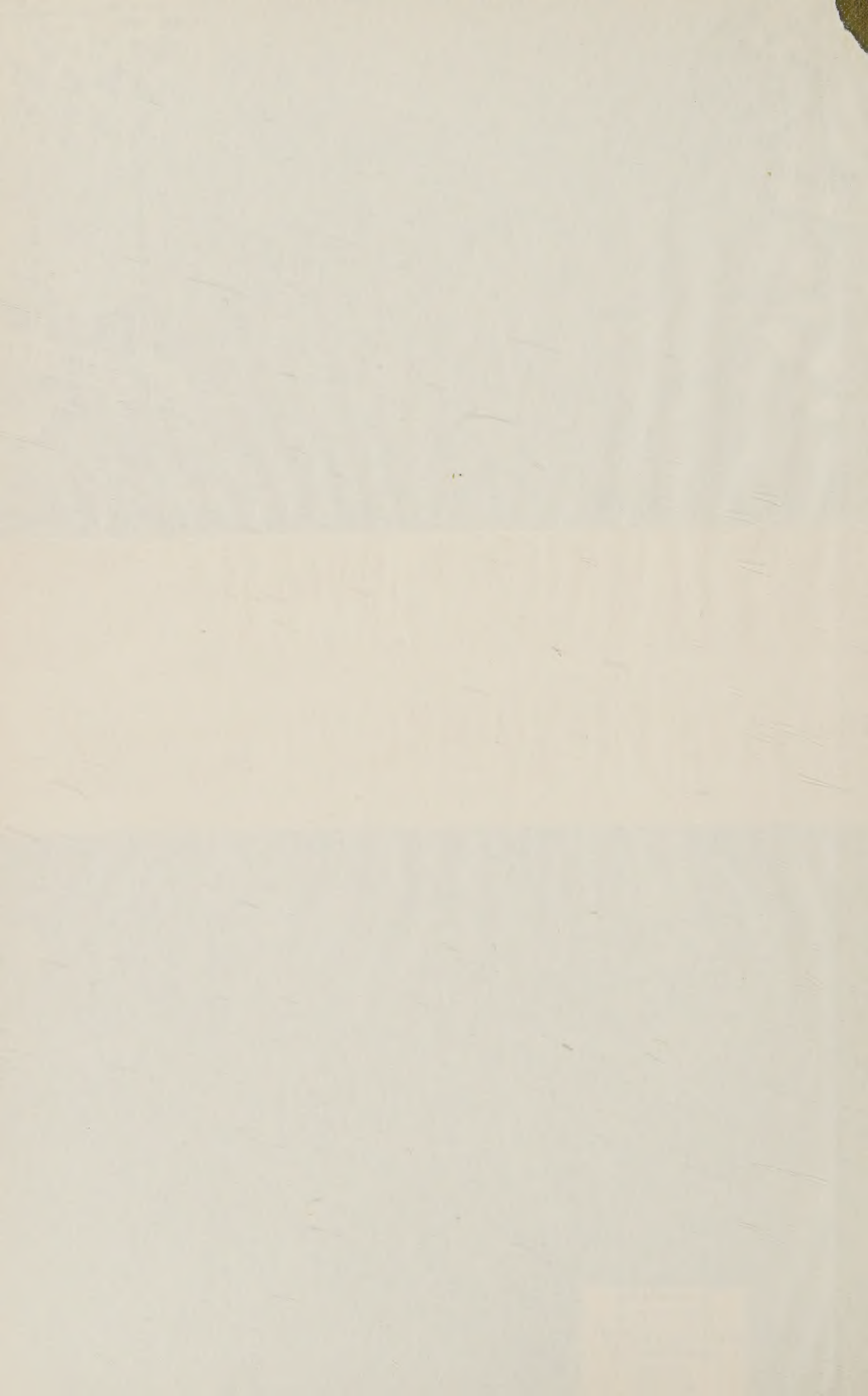


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PROGRESS IN LAKE AND STREAM IMPROVEMENT

By Clarence M. Tarzwell

Institute for Fisheries Research, University of Michigan

Various methods have been used to maintain and to build up our supply of game fish. Efforts were made very early to improve the fishing by the introduction of exotic species. This resulted in marked success in some instances, but in others it ended in failure. As changing conditions allowed more leisure time, and as roads and methods of transportation improved, the fishing pressure became so great that it was necessary to enact protective legislation to prevent the complete removal of our game fishes. Certain seasons, bag limits, and size limits were set.

Concurrent with the formation of protective legislation, propagation of desirable species was undertaken for the restocking of depleted waters. This latter movement has grown until today we have our modern and efficient hatchery plants, our rearing stations, and our rapid and modern methods of transporting the fish. For a time it was thought that the problem could be solved simply by planting large numbers of fish, and by regulating seasons, bag limits, and size limits. The influence of propagation was so great, in fact, that there has been a tendency to judge fish conservation almost solely by the number of fish propagated and planted.

OVERLOOKED BUILDING UP ENVIRONMENT

A great portion of the fishing public came to regard stocking as the panacea for all fishing ills; and the success of a fisheries program came to rest on the numbers of fish which were reported as planted. Very little thought was given to the establishment of suitable environments in which to plant fish, in fact, it was customary to dump in the fish at points of easiest access.

Certain individuals, however, began early to see the weakness of such a program—namely, that emphasis was being placed on the number of fish reared rather than on the number taken later by the fisherman. It was recognized that propagation and protection, alone, cannot grow large fish; and that some attention must be given to the fish after planting to assure them suitable surroundings for growth, survival, and reproduction.

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As early as twenty-five years ago, various attempts to improve fish habitats were made by certain interested individuals and sportsmen's clubs. These efforts were largely directed toward the installation of fish shelter. This work was the initial of habitat improvement in this country. Although a beginning was made, and some fine pioneering work was done, this work did not spread rapidly nor widely because of certain handicaps. The facts that the workers were scattered and did not exchange ideas, and that they were not trained in fisheries biology, confined the work to a mere beginning in environmental improvement.

DID NOT GET BROAD VIEW

Most of the men were also handicapped by the fact that, in limiting their efforts to a single water, they did not get a broad view of the subject nor come to understand all the environmental factors involved. Usually only one kind of improvement device was used and this was suitable only for the water in which it was developed. This restricted practice led to failure when devices used in one type of water were introduced into other regions having different conditions and in which entirely unlike remedies were needed.

In 1927, Dr. Jan Metzelaar began some "re-snagging" work in Michigan streams. His method was to fell large trees across a stream, then to throw logs, poles, brush, and stumps into the stream and allow them to float down to form a jam. Each jam caused a hole to form and made cover.

It is apparent from the foregoing that the methods heretofore undertaken were designed only to meet certain conditions. A greater scope and broader experience was, therefore, needed for this work.

NEEDED COMPREHENSIVE STUDY

Before the work could progress, it was necessary that it be taken up in a scientific way, by the study of a number of waters in order that various kinds of improvement devices might be designed and a technique devised which would make the work applicable and of real benefit over considerable areas. The best way to meet these requirements would be to have the work sponsored by a state department or a separate organization which would retain an individual to study many waters of different types. Such requirements were met with the establishment of the Institute for Fisheries Research at the University of Michigan in 1930 as the research bureau for the Fish

Division of the Michigan Department of Conservation. The director of the Institute, Dr. Carl L. Hubbs, with characteristic foresight and energy, had recognized the need for such work, and immediately set about to attack this problem.

Mr. R. W. Eschmeyer was placed in charge of the lake survey, which had as one of its problems the discovering of the factors necessary for good fish production. This, in turn, demonstrated the deficiencies or absence of certain necessary conditions, and thus led to the restoration of these factors through lake improvement.

The task of devising methods for the improvement of streams was assigned to the speaker. This problem presented three phases: first, the determination of environmental factors necessary for good fish production; second, the discovery of those factors which were absent or out of balance, thereby limiting fish production; and third, the devising of economical and relatively permanent means for restoring these factors to their correct balance. Stream surveys were begun promptly and, later on in the season, actual improvement work was undertaken in the Little Manistee River in Michigan.

IMPROVEMENT WORK WIDENED IN SCOPE

During 1931, the improvement work was widened in scope, and several lakes and streams were improved. In 1932 the work was carried on in other waters, and broadened to include the states of Wisconsin and Iowa. 1933 saw an immense expansion of the work. This was mainly due to the increased interest produced by the Institute bulletin—"Methods for the Improvement of Michigan Trout Streams," published in 1932, and to the opportunity of using N. I. R. A. and E. C. W. funds and C. C. C. labor. Much lake and stream improvement was done in Michigan and Iowa. Improvements were also carried on in California, Arizona, New Mexico, Colorado, Wyoming, North Dakota, Montana, New York, Connecticut, Pennsylvania, Ohio and New Jersey.

In 1934, plans were extended and a more intensive program was begun. The U. S. Bureau of Fisheries received an appropriation for the conducting of lake and stream surveys, and the planning of lake and stream improvements in the national forests. The actual improvements were carried out by the Forest Service, in the national forests of California, Arizona, New Mexico, Colorado, Wyoming, Montana, Utah, Nevada, North Dakota, Minnesota, Wisconsin,

Michigan, Virginia, West Virginia and North Carolina. Work was also done by the states of Iowa, Michigan, Connecticut, Pennsylvania and New York.

It becomes apparent that the field of environmental improvement has experienced a rapid, almost startling growth since 1930. This spreading of the work has benefitted it in many ways. It has widened its range, presented many new problems and led to the development of new methods to meet new conditions. A better understanding has been gained of the aims, purposes, and needs of habitat improvement.

CREATE MORE FAVORABLE CONDITIONS

Habitat improvement has come to consist in the deliberate creation of conditions more favorable to fish production. It is being developed on the theory that protection and propagation alone cannot bring about the maximum fish production in our waters. We are now approaching the problem in a more scientific and objective manner.

In the early stages of improvement, only pools and shelter were considered. Now we are studying all the environmental factors, with the intention of supplying them when they are lacking, or of restoring them in the proper relation to other necessary environmental conditions when they are out of balance. Environmental improvement has come to mean, then, the creation, maintenance, and development of surrounding conditions which are essential and conducive to the growth, reproduction and well being of the desirable game fish of our waters.

ESSENTIAL FACTORS FOR PRODUCTION

It is obvious that before one can hope to improve environmental conditions for fish life, it is necessary to know the elements which are indispensable to the survival, growth and reproduction of the fish it is desired to encourage.

The widening of the extent of the work presented opportunity for the study and determination of the necessary environmental factors. Those judged to be basic for the suitable production of fish may be grouped under four main heads. These are: (1) suitable water supply; (2) adequate spawning conditions for the desired species; (3) sufficient and proper food for all age classes of desirable fish, and

(4) suitable resting places and shelter for all age classes of the encouraged fish.

In order to be accordant with fish life, the water supply must be relatively pure and free from harmful substances. The water should not be so pure, however, that it lacks the fertilizing materials necessary for the production of food. The water must also be of a temperature within the limits tolerated by the particular fish being encouraged. For the trout it should be cold enough not only to permit the trout to survive, but also to hold disease and competitors in check; and yet it should be warm enough to produce a good growth. For bass it should be warm enough to promote the abundant growth of food organisms, and should not be subject to extreme fluctuations which would destroy the spawn.

In lakes, the water should be of such a depth that winter conditions do not become unfavorable. Water levels should not be subjected to extreme variations. In streams, the flow should be relatively constant and of sufficient volume throughout the year.

SHOULD BE FIT SPAWNING AREAS

In regard to spawning, there should be adequate and fit spawning areas for the desirable species, as well as for the species which serve as food for them. There should be free access to the spawning areas and temperatures should be favorable for production of young. Spawning areas should be so located that they will not be subjected to ice action or to harmful variations in water levels or temperatures.

Food is a very important factor in the production of fish. There must not only be an abundance of food for the adults, but there must be types of food suitable for all age classes of fish. Food must also be available for the organisms which serve as the food of fishes, if these organisms are to maintain themselves in suitable abundance. A balanced food cycle is of outstanding importance.

Shelter is essential for all age classes of the game species in order that they will remain in the desired locations in sufficient numbers and to protect them from their enemies of the air and water. Some attention should also be given to providing shelter for the species which serve as food for the game fish, in order that their numbers be maintained.

As the study of environmental conditions progressed it became

apparent that certain original conditions were unfavorable and that conditions brought about largely by the activities of man were operating to destroy the essential environmental conditions or to throw them out of balance. These detrimental factors may be designated as the basic reasons for lake and stream improvement. They may be classified under two main heads. First, natural deficiencies inherent in our lakes and streams, and second, unfavorable conditions brought about largely by the activities of man.

Natural deficiencies are the inherent conditions in our lakes and streams which for long periods of time have reacted unfavorably toward fish production. Among these may be listed absence of shallows and spawning areas, shallowness of water and infertility.

While it is often considered useless to try to improve on nature, it is now believed it is possible to do this in many lakes and streams. In view of the fact that our lakes and streams were formed by natural processes and were not created or especially designed for the species of fish which we desire, it is logical to believe that with adequate knowledge and a definite design or purpose in mind, we can improve on nature and make some of our waters more favorable for the desired species.

Detrimental conditions brought about either directly or indirectly by the activities of man are largely caused by deforestation, fire, over-grazing, erosion, cover removal, pollution, use of water for irrigation, power projects, hydraulic and certain other types of mining, excess drainage and unwise recreational practices. Some of the ways in which these have changed conditions in our lakes and streams will now be discussed.

REASONS FOR LAKE IMPROVEMENT

Under forested conditions high trees were continually falling out into the lakes and thus furnishing cover for both large and small fish. When these trees were removed for lumber or were destroyed by fire this source of cover was removed. In time these trees which were already in the lake disappeared through the action of natural agencies and the lake became barren of cover.

With the removal of forests an effective wind break was destroyed and wave action increased. Often this resulted in the erosion of the shores and the addition of immense quantities of undesirable soil materials to the lake. Shore erosion was also accelerated by the re-

moval of trees along the shore whose roots tended to hold the shore materials in place. Wide barren shallows were built up of the material eroded from the banks. These shallows are subject to severe wave action and plant beds, cover, food producing areas and spawning beds are damaged or destroyed.

SILTING DESTROYS HABITAT

Deforestation, fire and over-grazing has often resulted in severe erosion in the region of the lakes and caused the addition of great amounts of undesirable soil materials which have covered and destroyed food producing areas and spawning beds. Excessive drainage, the lowering of outlets, the use of water for irrigation and the lowering of the water table has brought about the lowering of lake levels to such an extent that in some instances shallow water areas have been destroyed or decreased with the resulting destruction of the habitat of many of the forage fish and the young of the game fish. The principal spawning and food producing areas are likewise injured. Fluctuations in water levels due to power dams and to floods and periods of low water in feeder streams bring about the same harmful results.

Resort activities sometimes react unfavorably to good fish production through the cleaning up of the lakes. Cover and plant beds are removed in order to create clean bathing beaches. Bathers often disturb spawning and nesting fish and destroy nests. Motor boats may also exert a detrimental influence particularly at spawning time.

REASONS FOR STREAM IMPROVEMENT

Conditions which react unfavorably to our lakes have also produced undesirable conditions in our streams. Deforestation, over-grazing, fire and drainage have increased surface run-off and decreased spring flow. This has resulted in great seasonal fluctuations of flow, as surface water passes off very rapidly and creates severe floods. Due to this increased surface run-off streams become very low or even dry up during periods of scant precipitation, as the flow of springs is reduced. Floods roll and grind the bottom materials with the resultant filling of pools and the destruction of plant beds, spawning areas and food organisms. They often destroy the stream banks and convert the streams into wide, shallow stone washes, which are devoid of pools and cover. Then, during low water periods, large areas of the stream beds are exposed to desiccation with the resultant destruction of insect life.

The agents which have operated to produce more severe floods have also tended to accelerate erosion. Tons of sand and silt are being washed into our streams each year, causing the filling of pools, the covering of spawning beds and the destruction of plant beds and food producing areas. Unwise farming practices are also responsible for the addition to our streams of tremendous amounts of soil materials.

COVER ALMOST DISAPPEARED

Cover has almost disappeared from many of our streams. Deforestation has removed the source of the materials which largely serve as hides, while floods and lumbering practices have removed the cover which was in the stream.

There are also other factors which have tended to destroy or throw out of balance environmental conditions necessary for good fish production. Clearing for farms, pasturing along streams and the removal of stream-side trees and shrubs have resulted in accelerating bank erosion and in some cases disadvantageous warming of the water. Power dams have interrupted spawning migrations while fluctuations in flow due to power uses and irrigation have decreased food production and reacted unfavorably to spawning activities and the production of young. Mining operations along streams have often destroyed the stream bed and banks, thus ruining certain sections for fish production. The increase in surface run-off and the decrease in spring flow coupled with the removal of shade, has often brought about unfavorable increases in the temperature of streams.

METHODS OF ENVIRONMENTAL IMPROVEMENT

From the foregoing facts, the need for at least partial restoration of environmental factors is apparent. Various methods have been developed for accomplishing this end. Each section of the country has different problems which require specific remedies. In fact, the work has progressed to such a stage that in certain localities which have been neglected by nature we have gone ahead to supply the necessary conditions, and in some instances as in Iowa, have formed artificial bodies of water by damming streams.

In lakes without an outlet little can be done to control water levels. However, in those having outlets conditions can be modified

in a number of ways. If the water is too shallow and winter killing results it can be made deeper by placing a dam at the outlet. Work of this nature has been done in several states.

When a lake is deficient in shallows a dam can be installed to raise the water level and produce shallows by flooding the surrounding country, if it is somewhat flat. Dams are also of use in maintaining a constant water level for the purpose of keeping the rich shallows, plant beds and spawning areas constantly covered.

Erosion of the territory surrounding lakes can be controlled by reforestation, fire protection, regulating grazing and gully control. Work of this nature has been carried on by the U. S. Forest Service and certain state agencies. While this type of work cannot be considered primarily as lake improvement it will result in improvement for many of our lakes.

Shore erosion by wave action can be somewhat controlled by building jetties to prevent shore currents and by constructing wave breakers to break the force of the waves. Work of this nature has been carried out in Iowa as a part of the improvement of the artificial lakes which they are making. The planting of trees along shores will also aid in preventing wave action as their roots tend to hold the soil in place.

PLACE GRAVEL FOR SPAWNING

In many waters situations unsuitable to spawning have come about due to the exposure of the shallows, or to great fluctuations in the water level. In some cases this can be overcome in the manner described for regulating water levels. Often there are lakes in which there are no spawning areas for game fish due to the absence of gravel. When this situation occurs gravel for spawning can be placed in the lake at suitable places. If the lake bottom is so soft that gravel sinks into it, the gravel can be placed in shallow boxes of a suitable size and then lowered into the lake at suitable points.

Fertility, vegetation and forage fish are the principal factors in the food problems of our lakes. While some fertilizing has been done, this method of increasing production is in a very early stage of development and no statements of results are justified at this time. Vegetation can be encouraged by the installation of structures which reduce wave action, and produce quiet areas suitable to the growth of aquatic plants. These structures may be in the form of

wave breakers which tend to produce quiet areas near shore, or they may be hollow squares made of logs, poles and brush, which are placed on the lake bottom. In situations where desirable aquatic vegetation is absent actual plantings of desirable species can be made. Such plantings which have been made in Michigan have to date been quite successful. A number of structures for encouraging plant beds have been placed in numerous Iowa and Michigan lakes.

INCREASE PRODUCTION OF FORAGE FISHES

Attention has also been given to increasing the production of forage fishes as a means of improving food production. This is done by producing shallows, furnishing cover and supplying spawning conditions suitable for forage fishes it is desired to encourage. Slabs and other flat structures have been placed along lake shores as spawning places for the blunt-nose and fat-head minnows which lay their eggs on the underside of such objects. These structures have been readily used by the minnows and production thus increased.

Lake improvement by the addition of shelter has been carried on quite extensively in Michigan and Iowa. These shelters are of various types and are made of brush, poles, rocks, or logs. Usually they are placed in shallow water at or near the drop-off. But in some instances they are placed in relatively deep water. In Michigan many shelters have been installed when the lakes were covered with ice, as this simplifies the work. In the artificial lakes which were constructed in Iowa, shelters and other improvement devices were constructed before the water was turned into the lake area.

METHODS FOR IMPROVING STREAMS

Agents operating to render environmental conditions unsuitable have been enumerated. Among these, fluctuations in flow and stream silting due to land erosion are outstanding. The simple installation of improvement devices in streams having extremes of flow, or rapid silting, is only a temporary remedy. It does not remove the cause of the unfavorable conditions and the agents which have brought about the improper state continue to act. If such streams are to be improved the original causes of the undesirable situation must be controlled and prevented from acting. The control of such detrimental factors will require a long time program. Floods and stream silting are being controlled by reforestation, fire control,

regulating grazing and erosion control. While these practices cannot be considered as coming under the head of stream improvement, they are being carried out in many parts of the country and are improving conditions by reducing floods, increasing low water flow and reducing erosion and stream silting. Thus, in many cases, the first step in the improvement of streams must be made, not in the streams themselves, but on the whole watershed.

In Montana, Wyoming and Colorado, small dams have been built on the head water streams for the purpose of storing water to regulate flow and to serve as rearing ponds for the young. In the high Sierras of California, due to rapid run-off, there are many streams which become dry, or almost dry in summer. It has been possible by placing dams across the outlets of headwater lakes, to store enough water so that a uniform flow can be maintained throughout the year. About 75 miles of stream have been reclaimed in this manner.

SHADE AIDS IN CONTROLLING TEMPERATURE

The controlling of temperatures has received considerable attention. In sections of the country where streams become too warm, various efforts have been made to keep them cool. Spring feeders and springs have been cleaned out and shaded so their waters can reach the main stream quickly and at as low a temperature as possible. When shade is lacking trees and shrubs can be planted or encouraged along the banks. These will not only give shade, but will reinforce the banks against erosion and help to prevent excessive widening of the stream. (In New Mexico fences have been placed on each side of streams to keep cattle from destroying stream side vegetation and the banks. This is a very fine practice.) The draining of ponded areas and the confining of the stream channel by means of deflectors will tend to maintain low temperatures. A rather unique method of keeping a stream cool is to cool it by evaporation. This is accomplished by making it fall in a thin vertical sheet, so that it is broken up into a spray. This greatly increases the surface area and thus the evaporation which becomes so great that the stream is cooled. Cooling by this method has been accomplished in New Mexico.

PONDING MAKES WATER WARMER

However, in many mountain streams the water is too cold for good fish production and it is desirable to make it warmer. This can be

accomplished by the creation of ponded areas and back-waters so that a large water surface is exposed to the warming action of the sun. Such areas become quite rich and greatly increase production.

Usually improvements which aid natural reproduction are of real benefit. The production of young can be encouraged by the removal of barriers to spawning migrations. In Utah, falls which were barriers to fish migration have been removed and in Michigan channels have been made through wide sandy flats which were preventing the migration of large rainbows. Much can also be done to improve the spawning areas themselves since many of them have been impaired or destroyed by stream silting. Gravel areas can be uncovered and spawning beds restored by the removal of sand and silt through the use of deflectors.

Good food production is an outstanding necessity for good fish production. Quantitative bottom studies in our streams have shown that sand, clay and bed rock are poor in food, while gravel, rubble, silt and plant beds are rich in food. It is therefore apparent that if we wish to increase the production of food we must produce the richer bottom types. Considerable success has been obtained in this undertaking by the use of current deflectors. Gravel areas have been uncovered, silt and muck bars formed and plant beds produced by their use.

PREVENTS ADDITION OF SAND

In Michigan it has been found that shifting sand is quite barren of food. It is therefore desirable to prevent the addition of sand to the streams. The chief source of sand in Michigan streams is the large eroding banks which are continually adding sand to the streams. An effort has been made to reclaim these banks and prevent further additions of sand. The first step was to direct the current away from the critical area—that is the base of the banks. This was done by means of deflectors. Brush mats, quick growing vegetation and planting of trees are some of the methods used on the slopes to prevent slumping.

It is universally recognized that pools and shelter are necessary if we are to have good fishing. A great deal has been done in various parts of the country toward supplying these requirements. Deflectors have been used particularly in the Mid-West to cause the current to scour out pools in the stream bed. In locations where

the bottom is very hard and cannot be eroded rapidly dams have been installed for producing deeper water. This type of improvement has been extensively used in New Mexico and Arizona.

Shelter is also recognized as a requirement for fish life and many different devices have been used to provide hiding places for fish. Rafts, bank covers, trees, log jams, rock piles and underwater covers have been used with varying degrees of success, depending on the locality. The installation of shelter has been carried on quite extensively in various parts of the country—in fact the building of dams and the installation of shelter have been the chief forms of improvement to date.

DESIRED FUTURE DEVELOPMENTS

While the rapid growth of environmental improvement has been very gratifying, perhaps a warning should be sounded. The work has been undertaken over such wide areas that it has of necessity been supervised by inexperienced persons. Many feel that most anyone can supervise environmental improvement and a great deal of work has been done under that assumption. Often this has resulted in the installation of devices, which are not only useless but are actually harmful to the waters. It is very easy to harm a water by improper method of environmental improvement. This procedure will have a tendency to discredit environmental improvement, a condition which is indeed unfortunate, since it is felt that environmental improvement has real value and is a useful means and a necessary factor in the maintenance and upbuilding of our fish supply.

Before a doctor can prescribe remedies for disease he must be able to diagnose the disease. In the same way, one who is to improve conditions for fish life must know the environmental requirements of the fish and know how these requirements may be met, since the basic idea of improvement is to determine what factors are limiting the abundance of catchable fish and then to proceed to overcome or remedy these natural deficiencies. The degree of success obtained in the improvement of our waters rests as much on the discovering of the factors limiting fish production and on the wise planning of the improvement work as on the actual constructions used.

Another tendency which may react unfavorably to environmental

improvement is the tendency of many to regard it as the means of improving fishing conditions. It should be recognized that as in farm lands, we may have marginal and submarginal lakes and streams on which the benefits derived from improvement will not justify the cost of improvement. While the ultimate aim of improvement is to provide better fishing, it is not a "cure-all" for all fisheries ills. Protection, propagation and the control of predators and disease are other important and necessary factors in a sound fisheries management program.

Consistent and sound fish management can rest only on a knowledge of environmental conditions and of fish life. The technique of environmental control is still in a very rudimentary stage and much yet remains to be learned regarding the environmental requirements and the methods of supplying them in their correct balance. Further investigations are necessary. While over a million dollars have been spent on installing improvements only a few thousand have been devoted to actual investigation.

NEEDS OF FURTHER STUDY

Investigation is also necessary in the other branches of fisheries management. Protective legislation must rest on a sound knowledge of existing conditions. Our propagation system needs further study. While hatcheries and rearing stations have been brought to a high stage of development the other factor in the chain—namely—correct stocking, has lagged behind. Stocking practices must be put to every possible test along with testing the values to be derived from improvement work. Everyone recognizes the need for investigation in the field of disease and predators. Investigations must be conducted on all phases of fisheries management and a sound fisheries management technique built up, if a suitable game fish supply is to be provided for future generations.

DISCUSSION

DR. JOHN R. GREELEY [New York]: I really feel that this subject has been covered so broadly, that there is not really a good deal to be said to justify standing here and taking further time on the program.

I might say a few things about the work in New York. Since the work started with the C. C. C. development last April on a large scale, approximately 46 miles of improvements have been completed. New York State has a great number of small streams on state-owned lands, many of them near the C. C. C. Camps, and

we have picked those smaller streams and especially the ones which are poor, flat, and in need of various improvements.

I don't believe I can add a single thing to technique that has not been already covered here. I might say as far as technique is concerned, that stream improvement has gotten along in very good shape. The right sort of construction can be put in the wrong place, as a series of dams spaced too closely can illustrate. We have to constantly avoid that type of work.

We have to constantly avoid work that is unsightly; that the anglers might object to, because after all, fishermen come to the streams for enjoyment, and it might even be possible to do a successful improvement that might increase fish production, but might be unsuccessful from the point of view of recreation.

I don't think that there is anything that I can say, as I mentioned before, that hasn't been very well covered. The work has expanded very rapidly, and next year with C. C. C. labor, if everything goes right, we expect to improve approximately 150 miles of the smaller trout streams in the State. Thank you.

MR. OLIVER M. DEIBLER [Pennsylvania]: We have been trying to carry on this work. We have termed it by a different name. We call it stream farming, because we feel that it is just as obviously necessary to farm our streams as it is for a farmer to improve his farming conditions.

On account of the congested conditions in Pennsylvania, and the great number of fishermen, we find that after having made a careful survey of the mileage of our waters in Pennsylvania, that were all our trout fishermen out on one day, each man would have approximately 90 feet of trout stream in which to fish.

We found we were faced with the problem of creating conditions that we could grow two trout or three trout or four where only one grew before. As we all agree that food and shelter are quite as necessary, and that water is only a medium, as air is to us, we set out to try to create a condition that would supply these requisites.

Our first experiment was opened last year on a section of stream that the Board bought in Central Pennsylvania, the famous trout stream at Bellefonte. Many of you who have been to Bellefonte, have no doubt seen the wonderful natural exhibit of the large trout in the City. We purchased a mile and a quarter of that stream (not the trout) and with some welfare labor we were able to install all the devices that were suggested to us, or that we knew anything about.

I want to say that we got a great many of our ideas from our friends over in Michigan.

Then, in order to attract the fishermen to this place, so that they could see what had been done and could get ideas which they could carry back, we had to offer some attraction; just as men will attend any kind of a meeting if there is something to eat. So we had to offer some inducement to get the fishermen and those that were interested or whom we wished to interest in this work to come to Bellefonte.

After we had this stream project completed, we stocked it very heavily with the three varieties of trout—brown, brook and rainbow—all large trout, and invited the fishermen to come and enjoy some real fishing.

It was necessary, of course, to put very limited restrictions. We allowed the fishermen to catch the daily legal limit in Pennsylvania of 20 trout, but they could

only kill two and take them off the property each day. These two had to be 10 inches or over in size.

We did not neglect the ladies, either. We set aside a particular part of the stream for ladies only, and we saw to it that the men could not get even with the ladies for some of the back seat driving instructions that they had received. We kept the men away and allowed the ladies and girls to fish exclusively on a well stocked area of this stream. I believe this is one of the biggest investments that we made, because we sold some 500 licenses to ladies and girls who had never fished before.

We limited the number of days that the fishermen could fish to five each season, for the reason that had there been no limit we know the fishermen in the immediate vicinity would possibly have taken undue advantage of the set-up. As it was, all the fishermen in Pennsylvania had an equal opportunity.

I might say that in the nine weeks that we operated this, we had 4,880 fishermen. We prescribed the use of barbless hooks and artificial lures, no natural bait. The fishermen took to this proposition so well, that the final check-up showed that they had killed only 2,600 odd trout that they took off the property and had caught and released, put back into the stream, over 11,000 trout. They put back four to every one they killed.

I might say we kept a very careful check on the ones that died from the effects of having been caught, and it was less than 100.

The sportsmen came and visited this place and saw what could be done. I might tell you that in about nine counties of Pennsylvania, the Federated Sportsmen in those counties have, out of their own funds, supplied the material, in many cases all the labor. However, we were able to get some C. C. C. help, and we will have in 1935 between 600 and 700 miles of streams improved. Last year I don't know exactly how many miles resulted, but I do know there were quite a number, and the fact that we did allow them this particularly good fishing, did bring them out in large numbers who otherwise would not have been interested.

MR. CHARLES O. HAYFORD: We have done quite some stream improvement in New Jersey. We find in a state like New Jersey the snagging of streams adds a great deal to our stream life, and also gives us an opportunity to put out more fish per mile of stream.

In order to do that, we were fortunate enough to get a C. C. C. Camp. We have used them some on stream improvement, but largely in increasing the output of the hatchery. I don't know what the other camps have done, but our camp has done a wonderful job in New Jersey. Those boys move on an average of 50,000 yards of dirt a year. They have already built over a mile and a half of new ponds, and something like a mile and a half of good roads, besides laying nearly a half mile of pipe lines. They have increased one of our plants 42 per cent. The other one they will probably increase 30 per cent.

LAKE AND STREAM IMPROVEMENT IN MICHIGAN

By CLARENCE M. TARZWELL, Institute of Fisheries Research, Department of Conservation and the University of Michigan

During the past 3 years lake and stream improvement has had a rapid, almost phenomenal, growth in popularity and use. As most of the work has been made possible through the use of emergency funds it has been essential to organize and carry out the work as rapidly as possible. Many streams and lakes have been worked without first being surveyed and much of the work has been carried out under an inexperienced and untrained personnel. The lack of adequate information concerning the methods of construction, the purpose of the various structures and the ecological changes brought about by them has been keenly felt and clearly shown in a great deal of the work. In view of these circumstances it is felt that the experience gained in Michigan during the past 6 years may be a help to others engaged in a similar undertaking.

Ten years ago, when discussing the decline of fishing in streams old fishermen spoke of the cleaning of the streams for log drives as the possible cause of that decline. Some advocated replacing the logs, trees, and wing jams as a means of bettering the fishing. A further development of this was the "resnagging" work carried on by Dr. Jan Metzelaar in the Pere Marquette and Little Manistee Rivers in 1928 and 1929. This "resnagging" consisted of the felling of large trees across the streams and the throwing of various materials into the streams so that they would float down and lodge against these barrier trees to form jams. It will be noted that such work takes into consideration only the formation of pools and cover and no thought was given to food or spawning conditions. As these jams continued to grow, in time they became so large that the tree could no longer hold them and they went out. As such "resnagging" work was incidental to other activities it was not extensive. It was, however, a beginning, and demonstrated that pools could be formed but that the mere throwing of material into a stream was not enough to bring about permanent results.

In 1930 with the creation of the Institute for Fisheries Research under the direction of Dr. Carl S. Hubbs the work was taken up in a more intensive manner. A program of lake and stream surveys was initiated. Mr. R. W. Eschmeyer was placed in charge of the lake surveys and the lake improvements. The speaker was given the responsibility for developing, testing, and checking the results of various methods for improving trout streams.

In the summer of this first year the Michigan Department of Conservation made an appropriation for carrying on a project on the Little Manistee River in Lake County. Since this was the first

project of its kind in the State and, in fact, to the best of the speaker's knowledge, the first in the country the work was of necessity an experimental project. Many types of structures were installed in order that their action might be observed and the best ones selected. Among the more successful types the following may be listed: wing, V and I deflectors made of logs or stone, tepee and raft covers, trees, and bank covers. A number of stumps were used but about half of them were washed away due to faulty installation.

Notes were taken on the condition of the stream before the structures were installed. Type of bottom, plant beds, mucky areas, depths, cover, and size and depth of pools were all noted as well as the type and construction of the device. Each device was tagged with a numbered metal tag so that future observations could be made. In all, 500 structures were described, tagged, and located during the first season.

In 1931 a recheck was made of the previous year's work and a knowledge was gained of what each structure could be expected to do. With this information as a working basis and with a better knowledge of the requirements of the trout and the deficiencies of the streams the work was continued in a more systematic manner. Devices were installed not only for the purpose of creating pools and cover but also to improve food conditions by producing riffles uncovering gravel areas, and creating mucky areas and plant beds. Various types of deflectors, such as V's, Y's, I's and A's, were used to bring about these conditions and also to create pools. Cover was furnished by various types of raft, bank, bend and center covers. Attention was given to the prevention of bank erosion by the use of large boom covers and bend covers. As in 1930 extensive records were made of each installation and its surroundings.

While it was possible to observe the formation of pools in a stream, further and more definite information was desired as to just how the so-called improvement devices influenced the fish population and the food. In order to secure this information, fish counts and food counts were made before the devices were installed. The location of these various counts were recorded so that recounts could be made some years after improvement when conditions again became more stable.

The fish counts were made by enclosing a portion of stream by barrier seines placed at the upper and lower ends of a selected section and then catching the fish in the section by the use of small seines. The barrier seines were held by means of stakes driven into the stream bed. Chicken wire was stretched across the stream in front of the stakes in order to give added support to the seines. This arrangement made it possible to hold the seines until all the fish in the section had been caught, measured and recorded.

The food counts consisted of quantitative bottom samples. These were made by collecting all the bottom organisms from a unit area. These organisms were preserved for future study. Counts were made at locations where devices were to be installed and a record of bottom type, depth, and surface current was secured. In this way it was hoped to obtain information concerning the manner and the extent to which food production was influenced or changed by the devices. Counts were made on the East Branch of Black River, Pigeon River, and Gamble Creek.

During the following year the work was continued and expended to streams in various localities. Rechecks were also made of all previous work and the ecological conditions noted. Underpass deflectors were found to be very efficient in the formation of pools. Wing deflectors proved to be most effective in the creation of muck areas and in the establishment of plant beds. Large boom covers and raft covers were found to be unstable as they were carried away by floods or they waterlogged and sank so that they became useless. Bank covers, square covers, tepee covers and wedge covers were found to be unsatisfactory in streams having a good deal of ice. In such streams it was necessary to submerge these covers below the ice level or ice forming around them would pull the stakes due to its lifting action. In constructing the submerged bank covers it was found to be well to imbed the holding legs into the bank at least as far as they projected into the stream. In general, deflectors were not affected by the ice, but it is well to keep them low and to bank them on the upstream side. V and Y deflectors were found to be especially useful for uncovering gravel by the removal of sand. This is one of the means of increasing food production. Wing deflectors, jam jams, and large bend covers were found to be effective in preventing bank erosion.

Except in certain locations stumps proved to be difficult to hold in place. In sandy bottom streams they often completely washed out the stakes holding them and in streams having a good deal of ice the stakes were pulled. A good method of holding stumps in place under such conditions is to fasten them to a stake by means of a 10- or 12-foot cable. The stake should be deeply imbedded and the cable fastened to it just above the stream bottom. In order to prevent ice from forming on the stake it should be cut off just above the stream bed. The advantage of the cable is that it allows the stump to raise and lower without exerting a direct upward thrust on the stake. Care should be used when placing stumps on a gravel bottom as the sand bar formed below the stump will often more than offset the value of the pool formed.

During the period from 1930 through 1932 the lake crew was engaged largely in survey work. They did, however, carry on some experiments in the installing of brush shelters, gravel spawning beds, and slabs as spawning places for blunt-nose minnows. Some plantings of aquatic vegetation were also made. In the fall of 1931 brush shelters, gravel beds, and slabs were placed in several lakes in Kalkaska County.

In 1931 the scope of lake and stream improvements was greatly increased due to the fact that E. C. W. and F. E. R. A. funds were available for such work. The Institute workers became associated with the supervisory personnel and put to practice their findings, experience, and training for the purpose of carrying out further projects. Work was undertaken on several lakes and a number of streams. Brush shelters were installed in 18 lakes and some 27 miles of streams were improved. In addition to the installation of brush shelters aquatic vegetation was planted and gravel spawning beds were placed in several lakes. Slabs were also introduced to improve spawning conditions for certain minnows.

While construction work was emphasized, experimental work was not neglected. Records were kept of the devices installed in lakes,

and notes were taken on the ecological conditions before the work was carried out. An experiment was carried out in Tomahawk Lake to determine what devices were most suitable for encouraging the spawning of blunt-nose minnows. This lake was chosen because minnows were abundant there. Various types and sizes of devices were installed. It was found that the minnows preferred a slab or other flat object which was at least 6 inches wide and placed directly on a sandy bottom in 6 to 18 inches of water. Several will spawn on one slab and their eggs are often in one mass.

To date the planting of aquatic vegetation in lakes has not been very successful. When plants have been placed in barren lakes they died or became gradually smaller and weaker. These results have led to a feeling that most plants have sufficient means of dispersal and they occur naturally in lakes where conditions are suitable to their growth. Thus indiscriminate planting is not thought to be of much value. Proper plantings in artificial lakes are felt to be of value.

Experiments were conducted in Howe Lake, Crawford County, to determine the results obtained from the introduction of gravel to form spawning beds for bass. One hundred and three gravel beds were placed over a sandy bottom in $1\frac{1}{2}$ to $3\frac{1}{2}$ feet of water. These nests were observed during the entire spawning period. All nests which were noted were made on the gravel which had been added to the lake. It was observed that even though gravel piles were placed close together nests were not made closer than 8 to 10 feet from each other. The most favorable depth was 2 to 3 feet. There is also an indication that at least a bushel of gravel is required, since when a smaller amount is used the bass dig a deep bowl-shaped nest, probably in search of more gravel. If storms occur at spawning time such nests on sandy bottoms become partially filled with sand and are thus destroyed. There is reason to believe that these artificial nests improved spawning conditions. Previous to these experiments the lake was seined each year to secure young bass. Until the time of improvement 2,500 was the greatest number secured, while after the addition of the nests 15,000 were secured.

Investigations to determine the efficiency of the brush shelters have also been conducted. Seines have been placed around many of the shelters, and then the brush has been removed so that it was possible to catch the fish which were in or around the shelter. It is apparent that some fish are attracted to the shelters more than others. The normally free-swimming fish were not attracted to any extent, while those usually favoring weed beds were found around the shelters. Suckers, which were also abundant around the shelters, were probably attracted by the abundance of algae and other types of food. Crayfish and aquatic insects were especially abundant in the shelters. A large shelter with loose rough edges attracted large fish, while small, tight, smooth shelters never attracted large fish, but were inhabited by small fish. The large fish were adult bass and suckers, while the small fish were young bass, bluegills, rock bass, suckers, and minnows.

In addition to the 27 miles of stream improvement accomplished in 1933, bank-erosion control was carried out along the Pere Marquette River. Several methods were used to hold the upper portions of the banks and protect them from erosion by wind and rain. Ter-

races held by stakes and poles were used on some banks, while brush or poplar pole mats were used on others. On some banks, a more expensive method was used. The banks were given a uniform slope and then large logs were stood up so that they extended from the bottom to the top of the bank. Poles were then fastened to these logs at right angles and about a foot apart. Each of these formed a small terrace. Straw or rich soil was placed on these terraces and they were sown with various grasses and trees planted at frequent intervals. Of the methods used to date, the latter has proved to be most successful.

Since 1934, the institute has not been concerned with the actual construction work, as it was felt that field had been developed to a stage where it was no longer within its province. The institute has confined its efforts to an evaluation of the work, and has acted in an advisory capacity to give aid in biological matters and in the interpretation of results.

During the past 2 years the organization has been improved, and the extent of the work has been greatly increased. Mr. Roy Johnston, who is now in direct charge of the work, has kindly furnished data on the amount of work accomplished during this period. During the past two winters, brush shelters and other improvements such as gravel spawning beds and slabs for minnows have been installed in 180 lakes. In 1934, 118 miles of stream were improved, and in 1935, 132 miles of stream were improved. In addition to this work, in 1935 some 700 miles of stream were conditioned for future improvements. This conditioning work was confined to the slower streams of the Upper Peninsula, and consisted of the cleaning out of debris left from logging operations and the improvement of springs and spring runs by cleaning and the formation of definite channels. This conditioning work will in itself greatly improve stream conditions. In addition the erosion of sand banks along 22 miles of stream was controlled. The improvement crews were also active in the improvement of environmental conditions by the removal of beaver dams, 3,786 being removed from trout streams. There were 2,306 miles of stream opened for trout migration.

In 1934 and 1935 rechecks were made on fish counts and food counts. In those sections where it was possible to obtain goods counts it was found that either the total number or the number of legal fish had been increased. The rechecks on the food counts showed an increase in food production around the deflectors. An increase of as much as 40 times has been secured. The fast riffles and the mucky areas and plant beds have been found to be productive.

Environmental improvement is a problem in applied ecology. Every lake and stream presents a different problem and its improvement is not so simple as some believe. If we are to improve conditions effectively we must have a knowledge of the habits and know the requirements of the various species which we wish to encourage. Further we must know what necessary factors are lacking or out of balance. We must know how to restore them or put them in their proper relation to other factors necessary for good production. It is therefore apparent that an adequate survey of the waters must be made and experimentation, investigation, and elevation carried out to determine how the needs must be met. Fall, winter, summer, and spring conditions must be known before we can efficiently improve

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CLARENCE M. TARZWELL

U. S. Forest Service, Albuquerque, New Mexico



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EXPERIMENTAL EVIDENCE ON THE VALUE OF TROUT STREAM IMPROVEMENT IN MICHIGAN

CLARENCE M. TARZWELL

U. S. Forest Service, Albuquerque, New Mexico

INTRODUCTION

Although much stream improvement work has been accomplished and numerous papers have been written dealing with the methods of improvement, the evaluation of the results obtained has received little attention. Little or no experimental work has been done with the exception of that carried on in Michigan by the Institute for Fisheries Research. It is believed that more consideration should be given to a study of the permanence and utility of the various types of structures used for improvement work and to the physical and biological changes which they produce in a stream.

While engaged, since the summer of 1930, in the development of methods for the improvement of trout streams, the writer has endeavored to appraise each device and to evaluate its effect on environmental conditions. Many structures were installed primarily for experimental research. The rechecking and evaluation of the various types of stream improvement devices formed the principal part of the investigations carried on in 1931.

OBJECTIVES AND METHODS

Three main objectives sought in testing and evaluating stream improvement devices were:

1. The determination of the most permanent, economical, and effective structures for different types of streams and different situations.
2. The ascertainment of the physical and biological changes produced by each type of stream improvement device.
3. The evaluation of the physical and biological changes produced.

In order to obtain basic data for repeated checking, it was deemed necessary to record the stream conditions before improvement and to take complete notes on the structures which were built. Special forms were devised for these notes. Each structure was marked with a numbered, non-corrosive metal tag and located by its distance from other structures. The size and kind of materials used in each structure were recorded. The extent of the bottom types, such as sand, gravel, rubble, muck, and plant beds, were noted as well as soundings of depth across the stream at one yard intervals, and the number, size, and depth of the pools. Since it was known that some types of bottom are more productive of fish food than other types, the area of different

bottom types in the region of each installation was especially noted. These records, taken when possible at different seasons over a period of several years, made it possible to determine the extent of the physical and biological changes produced by the structures, the importance of these changes from the standpoint of trout production, and the efficiency of the structures.

Several methods were used to evaluate the physical and biological changes produced by the devices. Quantitative studies of the fish food organisms on various types of bottom were made so that the relative productivity of each could be determined. Counts of the organisms were also taken at the sites of the barriers both before and some time after installation. In addition to the counts of organisms, quantitative analyses of the fish population were made in certain sections of stream before and after improvement. Creel census records were kept for the East Branch of the Black River before and after improvement to determine changes in fishing returns.

EFFECTIVENESS AND PERMANENCY OF STREAM IMPROVEMENT DEVICES

Notes have been taken and rechecks made at all seasons of the year on a total of 2,235 barriers located in eighteen different Michigan streams. In addition, observations have been made on structures in the mountain streams of several western states as well as on the construction done by the Michigan Emergency Conservation Workers. The numerous examinations have supplied data bearing on the stability, utility and comparative cost of the different types of barriers.

As a result of these studies, certain conclusions have been reached concerning the effectiveness and desirability of the various types of devices which have been used, and the materials from which they have been built. Oak and tamarack have proven most suitable for stakes. Sound timber, dead or fire-killed, is most desirable. Pine logs or "dead-heads" have proven best for log deflectors, whereas cedar has been found most satisfactory for covers. Tree covers, slanting log covers, the various kinds of submerged bank covers, underpass deflectors and various sorts of wing deflectors made of logs or boulders have proven to be the most satisfactory types of stream improvement devices under most stream conditions. Underpass deflectors have been particularly effective in forming pools. The simple log dam with end cribs and the board dam were found to be the most successful kinds of dams.

The type of stream, it has been learned, determines the sort of improvement devices which should be used. For example, stone deflectors are undermined and quickly rendered useless in sand-bottomed streams; however, where the bottom is firm and large stones are available stone deflectors are preferable. Streams which flood severely require special structures and more bank protection than streams which are not subject to high water. When dams are placed over soft bottoms, such as

are found in many Michigan streams, great care must be taken to prevent undercutting. In this State, dams often cause deposits of barren sand that cover large areas of productive gravel, and destroy the pools. In some streams, "Y," "A" and "I" deflectors can be used to advantage.* Large boom covers and raft covers have been found unsatisfactory on most streams. Rectangular bank covers held by stakes, square covers in the center of the stream, tepee covers and wedge covers, when placed at the surface of the water, are unsatisfactory in streams subject to heavy ice. In such streams all cover devices should be so placed that they will be submerged at the winter levels of the water. Center covers have not been found satisfactory in streams which are subjected to either severe floods or ice action. Although center covers are usually most effective when totally submerged, submerged covers held down with boulders have shown a tendency to become filled underneath in streams which carry large amounts of sand.

Wing deflectors have proved most effective in creating mucky areas, encouraging plant beds, uncovering gravel when it is covered with sand, and in producing gravel and rubble riffles. One of the chief functions of deflectors is to create bottom types which are more productive of fish food. Deflectors built with extremely long directors produce large, thin, mucky areas which are not stable and which produce less food than the original bottom. Wing deflectors, wing jams, slanting logs and trees, and bend covers have been found effective in preventing bank erosion. Brush placed below deflectors is very helpful in building bars which decrease the width of the stream.

With the exception of the structures built the first year (1930) in the Little Manistee River in Michigan, only a few have been lost. Since the work on the Little Manistee River was the first to be undertaken many errors were made and about 30% of the structures installed were lost in five years. During the past five years the loss of structures in the other streams under observation has been as follows: East Branch of the Black River, 2.8%; Gamble Creek, 1%; Pigeon River, 10.6% West Branch of the Sturgeon River, 2%; Salmon Trout River, 4.7% and Black River, no loss. Stumps and raft covers composed a large percentage of the loss. The relatively large loss in the Pigeon River was due to the heavy ice action.

EVALUATION OF BIOLOGICAL CHANGES PRODUCED BY THE IMPROVEMENT DEVICES

The change produced by the various improvement structures in the physical and biological conditions of the stream, as related to game fish production, is considered to be a measure of the effectiveness of the devices. Deflectors have proven most successful in producing changes

* The various stream improvement devices have been described by Hubbs, Greeley and Tarzwell, 1932, "Methods for the Improvement of Michigan Trout Streams," Bulletin, Institute for Fisheries Research, No. 1, pp. 1-54, Ann Arbor, Mich.

TABLE 1. SUMMARY OF PHYSICAL CHANGES PRODUCED BY THE INTRODUCTION OF DEFLECTORS IN SIX MICHIGAN STREAMS

Item	Little Manistee River	East Branch, Black River	Gamble Creek	Pigeon River	West Branch, Sturgeon River	Black River
Average increase in av. depth of improved sections, inches	4.1	6.1	3.4	6.7	6.2	1 to 6*
Average increase in pool depth, inches	13.5	10.7	12.2	17.1	12.6	2 to 25*
New pools, number	280	128	76	120	99	17
Increase in pool area, square feet	5,309	13,744	....	....	....	....
Total amount of gravel area uncovered, square feet	37,265	10,340	6,454	26,010	600	....
Av. amt. of gravel area exposed by each deflector, sq. ft.	266	144	122	542	18	....
Total amount of rifle area produced, square feet	40,680	72,372	3,500	21,700	21,600	4,400
Av. amt. of rifle area exposed by each deflector sq. ft.	290	965	66	452	654	734
Total mucky area produced, square feet	21,650	29,445	4,565	14,640	8,095	6,640
Av. amt. of mucky area produced by each deflector, sq. ft.	154	392	86	305	263	1,100
Total area of plant beds produced, square feet	10,980	6,125	8,351	5,730	72,848	1,225
Av. amt. plant bed area produced by each deflector sq. ft.	78	82	158	119	357†	193

* The range rather than the average value is given because of the small number of measurements made.

† This is the average for the total number of devices, not for the deflectors only.

in the type of bottom found in Michigan streams. Since pools and shelter are essential for the production of a large number of adult trout, the success in creating good pools, the deepening and enlarging of existing pools, and the establishment of permanent and effective shelter serves as an important measure of the value of stream improvement.

The physical changes produced by stream improvement in six streams of Michigan are summarized in Table 1. Only the changes produced by deflectors are recorded in this table since nearly all the physical changes resulted from the use of these devices. Very often the original depth was increased several times. Deflectors were more successful in some streams than in others. In the East Branch of the Black River, each deflector produced on the average eighty-two square feet of plant bed, 392 square feet of mucky area, 965 square feet of riffle, and uncovered 144 square feet of graveled area. A greater area of plant beds was produced in the West Branch of the Sturgeon River than in any other stream, decrease since the cover devices also caused plant beds to form in this stream. The average production of plant beds in this river was determined therefore by dividing the total production by the total number of all structures installed.

Each deflector produced on the average 2,027 square feet of improved bottom in the Black River and 1,418 square feet in the Pigeon River. Since these new areas were from four to nine times as productive as the original bottoms, it is apparent that deflectors can be used to increase the production of food organisms.

Three methods were used for the evaluation of the biological changes produced by stream improvement: creel census, fish population studies, and quantitative studies of bottom food organisms. Creel census studies were undertaken on both the Pigeon River and the East Branch of the Black River, but only the returns from the East Branch of the Black River were complete enough to be usable (Table 2). The results indicate that the fishing was much improved after the installation of improvement devices, although such factors as natural fluctuation and migration might have been involved. The time available and expense incurred in making accurate fish counts, before and after improvement, limited the number of counts to four, too small a number on which to draw positive conclusions. It is significant, however, that in all tests made more legal trout were taken and the average size of the trout was greater after improvement.

Quantitative food studies made before and after improvement showed definitely that food production is greater on the type of bottom produced by the improvement structures than on the original bottom. The counts indicate clearly that the types of bottom exposed (gravel and rubble) or produced (mucky areas and plant beds) by deflectors are the most productive. The 447 counts made on six different streams of Michigan are summarized in Table 3. The data are a combination of counts made before improvement, after improvement, and in unim-

TABLE 2. SUMMARY OF CREEL CENSUS RETURNS FROM THE EAST BRANCH OF THE BLACK RIVER, MICHIGAN

Item	Before Improvement	After Improvement
Total number of legal trout caught	71	250
Total time fished (hours)	75.75	167.5
Number of legal fish per hour	0.936	1.495
Number of undersized trout per hour	4.74	3.08
Average length of fisherman's day (hours)	1.64	3.44
Average number of legal fish caught per fisherman's day .	2	5
Average size of all fish caught (inches)	4.7	8.7
Per cent of failures	19	7
Per cent of undersized trout in total catch	79	68
Per cent of legal trout in total catch	21	32

proved areas. The data show that the sand areas produce the fewest organisms. If sand is given the population rating of 1, the relative productivity of the other bottom types was found to be as follows: marl, 6; fine gravel, 9; sand and silt, 10.5; gravel and sand, 12; sand, silt and debris, 13; gravel and silt, 14; *Chara* and silt, 27; *Potamogeton pectinatus*, 28; rubble, 29; coarse gravel, 32; *Chara*, 35; mucky areas, 35; medium gravel, 36; *Potamogeton filiformis*, 43; gravel and rubble, 53; sand and gravel with plants, 67; muck, sand and plants, 67; moss on fine gravel, 89; moss on coarse gravel, 111; moss on gravel and rubble, 140; *Vallisneria*, 159; *Ranunculus*, 194; Watercress, 301; and *Elodea*, 452. These relative population ratings show clearly how food production in a sand section of a stream may be increased by a deflector which uncovers gravel and which produces mucky areas and plant beds.

TABLE 3. SUMMARY OF THE AVERAGE VOLUME AND NUMBER OF ORGANISMS FOUND PER UNIT AREA ON VARIOUS BOTTOM TYPES IN THE SIX MICHIGAN STREAMS STUDIED, BASED ON 447 BOTTOM SAMPLES

Type of Bottom Sampled	Rubble	Gravel and Rubble	Coarse Gravel	Medium Gravel	Fine Gravel	Moss, Gravel and Rubble	Moss on Medium Gravel	Moss on Fine Gravel	Sand and Plants	Gravel and Silt	Gravel Sand	Sand, Silt and Debris
Number of Samples	16	12	56	57	15	9	1	1	16	5	71	34
†Oligochaeta (Worms)	Vol. †	0.17	0.02	0.07	0.04	0.10	.....	.....	0.34	.....	0.03	0.09
Hirudinea	No.	4.37	0.25	3.31	3.03	12.30	.....	.....	34.10	.....	17.38	9.60
(Leeches)	Vol.	trace	.....	0.08	0.20	trace	.....	.....	2.08	.....	0.06	0.21
Gastropoda	Vol.	0.02	0.06	0.03	0.05	0.02	.....	.....	35.25	.....	1.49	0.40
(Snails)	No.	1.06	1.90	0.86	1.70	0.80	.....	.....	1.20	.....	0.08	0.02
Pelecypoda	Vol.	trace	.....	0.17	0.66	0.90	.....	.....	12.00	.....	1.41	1.50
(Clams)	No.	0.27	0.18	3.76	28.90	0.40	.....	.....	0.80	.....	0.46	0.05
Amphipoda	Vol.	.....	.....	0.23	0.13	0.11	.....	.....	8.00	.....	2.64	3.40
(Scuds)	No.	.....	.....	17.70	27.20	13.90	.....	.....	48.93	.....	0.71	0.01
Decapoda	Vol.	0.78	0.63	0.17	0.66	0.03	.....	.....	47.50	.....	0.93	0.20
(Crayfish)	No.	0.19	0.67	0.22	0.20	0.10	.....	.....	0.29	.....	0.19	0.27
Neuroptera	Vol.	0.29	0.68	0.07	0.05	0.04	.....	.....	0.19	.....	0.20	0.42
(Hellgramites)	No.	3.80	8.15	0.88	1.02	0.50	.....	.....	.....	.....	0.05	0.06
Ephemeroptera	Vol.	0.26	0.85	0.42	0.32	0.14	.....	.....	.....	.....	1.00	0.11
(Mayflies)	No.	43.48	265.60	130.60	117.90	7.20	.....	.....	0.61	.....	0.11	1.50
Odonata	Vol.	0.78	0.89	0.50	0.45	1.41	.....	.....	0.30	.....	0.28	0.17
(Dragonflies)	No.	5.60	8.50	3.44	2.40	10.00	.....	.....	231.30	.....	36.20	17.80
Plecoptera	Vol.	0.23	0.23	0.15	0.05	0.93	.....	.....	0.15	.....	1.24	0.09
(Stoneflies)	No.	6.58	23.13	4.27	5.03	1.00	.....	.....	1.18	.....	8.20	0.12
Hemiptera	Vol.	trace	.....	trace	0.02	.....	.....	.....	0.08	.....	0.01	trace
(True Bugs)	No.	0.14	.....	0.14	2.50	47.40	.....	.....	3.68	.....	0.13	0.10
Coleoptera	Vol.	0.02	0.12	0.05	0.05	0.35	.....	.....	0.02	.....	0.01	0.01
(Beetles)	No.	11.90	54.32	24.70	27.10	227.60	.....	.....	4.75	.....	0.17	4.00
Trichoptera	Vol.	0.81	2.04	1.91	0.85	0.19	.....	.....	0.40	.....	0.01	trace
(Caddisflies)	No.	138.16	563.50	245.70	116.30	8.18	.....	.....	80.00	.....	0.52	3.50
Diptera	Vol.	0.48	1.04	0.42	0.51	14.40	.....	.....	0.04	.....	0.11	0.56
(Flies)	No.	29.28	293.90	115.04	126.20	2.02	.....	.....	0.04	.....	0.10	1.30
Acarina	Vol.	.....	trace	trace	.....	458.60	.....	.....	8.78	.....	0.35	0.31
(Water-mites)	No.	.....	1.47	0.94	.....	210.00	.....	.....	0.86	.....	0.14	0.31
Petromyzonidae	Vol.	.....	.....	trace	.....	.....	.....	.....	235.30	.....	67.96	66.60
(Lampreys)	No.	.....	.....	0.06	.....	.....	.....	.....	.....	.....	trace	0.01
All organisms	No.	243.40	1221.60	4.24	4.07	1.15	.....	.....	0.69	.....	0.06	0.22
				555.58	466.58	18.10	.....	.....	0.81	.....	0.11	1.00
						14.25	.....	.....	8.74	.....	2.07	1.70
						357.00	.....	.....	743.53	.....	190.03	149.00
						728.00	.....	.....		.....		

*The Horse-hair worm, *Gordius*, was found in small quantity in the coarse gravel, *P. pectinatus*, and *Chara*.
†All volumes in cubic centimeters or fractions thereof.

TABLE 3—(Continued)

Type of Bottom sampled	Number of samples	14	14	Sand	Chara and Silt	1	8	1	Elodea Beds	Water-cress	Ranunculus	Vallisneria	Potamogeton pectinatus	Chara	40	28	2
*Oligochaeta (Worms)	Vol.	0.01	.....	.....	0.50	2.80	0.04	0.31	5.90	0.06	0.15	0.50	0.53	0.10	0.15	0.10	0.15
Hirudinea (Leeches)	No.	1.90	.....	.....	2.00	20.90	44.00	198.70	6282.00	222.00	1.00	15.80	403.60	5.70	1.00	5.70	1.00
Gastropoda	No.	0.51	.....	.....	1.90	0.15	0.36	0.07	.....	.....	.....	.....	.....	1.70	.....	1.70	.....
(Snails)	No.	2.30	.....	.....	22.00	4.00	4.00	1.33	.....	.....	.....	.....	.....	1.70	.....	1.70	.....
Pelecypoda (Clams)	Vol.	0.01	.....	.....	0.08	0.43	4.80	11.23	0.90	14.80	0.05	0.13	0.19	0.42	0.01	0.42	0.01
(Clams)	No.	0.36	.....	.....	6.00	58.10	132.00	214.70	48.00	744.00	1.25	6.10	6.74	9.37	0.05	9.37	0.05
Amphipoda (Scuds)	Vol.	0.05	.....	.....	0.06	1.15	1.40	3.27	1.00	2.30	0.18	0.27	0.38	0.39	0.01	0.39	0.01
(Scuds)	No.	6.40	.....	.....	6.00	0.88	120.00	364.00	14.00	544.00	1.00	44.32	18.48	27.30	0.05	27.30	0.05
Decapoda (Crayfish)	Vol.	.....	.....	.....	0.52	0.13	.....	2.57	.....	.....	0.15	0.26	0.97	0.34	0.47	0.34	0.47
(Crayfish)	No.	.....	.....	.....	72.00	0.21	.....	206.70	.....	.....	15.10	111.30	21.74	5.32	31.00	5.32	31.00
Neuroptera (Heilgrammites)	Vol.	.....	.....	.....	0.10	0.49	2.28	.....	3.00	.....	0.49	0.28	0.66	0.01	.....	0.01	.....
(Heilgrammites)	No.	.....	.....	.....	1.00	117.60	8.00	.....	2.00	.....	1.00	1.40	1.42	0.14	.....	0.14	.....
Ephemeroptera (Mayflies)	Vol.	0.01	.....	.....	.....	.....	0.40	0.27	0.61	0.20	0.09	0.06	0.05	0.22	.....	0.22	.....
(Mayflies)	No.	0.29	.....	.....	.....	.....	12.00	10.60	29.00	20.00	1.50	2.00	1.50	0.88	.....	0.88	.....
Odonata (Dragonflies)	Vol.	0.28	.....	.....	0.07	0.35	18.80	7.07	0.86	0.06	0.82	0.06	0.37	1.73	0.05	1.73	0.05
(Dragonflies)	No.	5.00	.....	.....	7.00	99.80	620.00	244.00	24.00	38.00	17.00	11.74	101.32	31.20	6.30	31.20	6.30
Plecoptera (Stoneflies)	Vol.	0.24	.....	.....	.....	0.03	0.40	0.59	2.25	0.10	0.25	0.06	0.45	0.56	.....	0.56	.....
(Stoneflies)	No.	0.78	.....	.....	.....	0.13	12.00	4.00	8.00	24.00	1.25	4.30	3.25	2.65	.....	2.65	.....
Hemiptera (True Bugs)	Vol.	0.03	.....	.....	.....	.....	0.44	0.05	0.05	trace	0.02	0.03	0.01	trace	.....	trace	.....
(True Bugs)	No.	0.64	.....	.....	.....	.....	24.00	1.33	3.00	4.00	0.25	1.90	5.20	1.39	.....	1.39	.....
Coleoptera (Beetles)	Vol.	.....	.....	.....	0.30	.....	.....	0.07	0.05	.....	.....	.....	0.15	0.02	.....	0.02	.....
(Beetles)	No.	.....	.....	.....	6.00	.....	.....	4.00	2.00	.....	.....	0.06	27.54	1.14	.....	1.14	.....
Trichoptera (Caddisflies)	Vol.	0.03	.....	.....	0.05	0.01	.....	trace	trace	trace	0.01	0.01	0.02	0.02	0.03	0.02	0.03
(Caddisflies)	No.	0.29	.....	.....	4.00	0.75	.....	2.67	9.00	4.00	0.50	0.80	6.34	18.50	11.50	18.50	11.50
Diptera (Flies)	Vol.	0.03	.....	.....	.....	0.41	1.60	0.59	0.11	1.00	0.03	1.57	0.79	0.20	0.02	0.20	0.02
(Flies)	No.	0.78	.....	.....	.....	16.30	40.00	12.00	12.00	4.00	2.75	1.22	78.04	17.70	3.00	17.70	3.00
Acarina (Water-mites)	Vol.	0.11	.....	.....	1.31	9.20	.....	9.80	1.00	1.10	0.18	0.17	0.61	0.33	0.05	0.33	0.05
(Water-mites)	No.	53.70	.....	.....	368.90	844.00	.....	966.70	329.00	162.00	15.25	68.00	186.70	91.30	16.00	91.30	16.00
Petromyzonidae (Lampreys)	Vol.	.....	.....	.....	0.13	.....	.....	.....	trace	.....	.....	.....	trace	.....	.....	trace	.....
(Lampreys)	No.	0.31	.....	.....	.....	.....	.....	.....	8.00	.....	.....	.....	7.32	0.57	.....	0.57	.....
All organisms	Vol.	0.71	.....	.....	.....	0.76	18.28	3.33	8.40	.....	0.75	0.74	0.04	0.29	.....	0.29	.....
(All organisms)	No.	1.62	.....	.....	.....	6.13	16.00	2.67	10.00	.....	0.75	1.10	0.28	2.80	.....	2.80	.....
	Vol.	73.15	.....	.....	.....	8.15	58.00	39.22	24.13	19.62	3.17	5.94	5.63	5.05	0.70	5.05	0.70
	No.	1.78	.....	.....	.....	706.10	1896.00	2233.40	6750.00	1766.00	58.60	289.54	875.92	217.16	69.10	217.16	69.10

A number of counts were made of the quantity of organisms found per unit area in three Michigan streams before and after improvement devices were installed. These samples were taken in the vicinity of the barriers in order to obtain a direct check on the different structures. The counts (Table 4), show that the volume of organisms per unit area was from three to nine times greater after stream improvement than before it.

TABLE 4. SUMMARY OF THE AVERAGE VOLUME AND NUMBER OF ORGANISMS FOUND PER UNIT AREA BEFORE AND AFTER IMPROVEMENT IN THREE MICHIGAN STREAMS

Name of stream	North Branch of Au Sable River		East Branch of Black River		Pigeon River	
Number of samples	24	40	16	27	8	10
Time in relation to improvement	Before	After	Before	After	Before	After
Oligochaeta .....Vol.*	0.12	0.42	0.08	0.40	.....	2.68
(Worms) .....No.	1.83	43.10	0.56	6.70	.....	2756.80
Hirudinea .....Vol.	0.68	1.86	.....	trace	.....	0.12
(Leeches) .....No.	5.25	39.50	.....	0.08	.....	6.00
Gastropoda .....Vol.	0.05	0.25	0.02	0.09	0.06	0.39
(Snails) .....No.	1.50	5.60	0.19	2.70	2.80	35.20
Pelecypoda .....Vol.	0.65	3.20	.....	0.20	trace	0.22
(Clams) .....No.	17.80	85.70	.....	2.30	0.10	33.40
Amphipoda .....Vol.	0.06	0.86	.....	trace	.....	trace
(Scuds) .....No.	8.60	120.70	.....	1.80	.....	0.40
Decapoda .....Vol.	0.74	0.60	0.04	0.08	1.08	0.60
(Crayfish) .....No.	0.33	0.60	0.31	0.44	1.00	0.40
Neuroptera .....Vol.	.....	.....	0.14	0.73	trace	0.48
(Hellgrammites) ..No.	.....	.....	1.06	13.50	0.10	11.90
Ephemeroptera .....Vol.	0.19	1.03	0.05	0.92	0.03	1.39
(Mayflies) .....No.	27.50	389.70	3.20	353.40	1.80	175.00
Odonata .....Vol.	0.23	0.58	1.24	1.23	0.02	1.08
(Dragonflies) .....No.	0.83	1.80	7.00	7.50	0.50	14.00
Plecoptera .....Vol.	0.03	0.10	0.10	0.54	.....	0.16
(Stoneflies) .....No.	0.67	5.00	1.40	34.60	.....	35.70
Hemiptera .....Vol.	0.01	0.19	.....	0.01	.....	0.01
(True Bugs) .....No.	1.58	36.10	.....	0.96	.....	0.40
Coleoptera .....Vol.	0.01	0.06	trace	0.16	trace	0.17
(Beetles) .....No.	2.37	28.10	0.56	114.50	1.90	68.70
Trichoptera .....Vol.	0.28	1.99	0.16	2.98	0.06	2.51
(Caddisflies) .....No.	18.50	170.50	8.70	967.70	11.00	433.70
Diptera .....Vol.	0.12	1.52	0.15	0.98	0.15	2.13
(Flies) .....No.	19.70	382.20	7.50	390.30	9.90	427.00
Acarina .....Vol.	trace	.....	trace	.....	.....	0.02
(Water-mites) .....No.	0.04	.....	0.30	.....	.....	15.40
Petromyzonidae .....Vol.	0.04	0.16	.....	0.13	0.08	1.68
(Lampreys) .....No.	0.13	0.20	.....	2.50	0.40	2.00
All .....Vol.	3.21	12.82	1.93	8.45	1.48	13.64
organisms .....No.	106.63	1308.80	30.78	1898.98	29.50	4016.00

*All volumes in cubic centimeters or fractions thereof.

In addition to the studies made in the vicinity of the barriers, investigations were also conducted on the food production in other sections of the East Branch of the Black River before and after improvement. When the improvements were placed in the East Branch of the Black River, two sections of the stream were more intensely improved than the others.

In the first improved section, which was located just below the lower dam and which had a fast current and a gravel and rubble bottom, forty-four deflectors, three dams, and thirteen covers were installed, comprising a total of sixty structures. This section of the stream is 5,634 feet long and has an average width of thirty-six feet, indicating an area of about 202,834 square feet. The barriers in this section produced 9,390 square feet of mucky flats which equalled 4.6% of the total area; 1,165 square feet of plant beds, equivalent to 0.25% of the total area; and 62,550 square feet of riffle which equalled 30.8% of the total area. Thus the improvements modified about 36% of the total area of this section of the stream. Since these modified areas are types of bottom which are rich in fish food, a considerable increase in food production could be expected. The counts of organisms made before and after improvement showed that on the average the mucky areas below the barriers had four times as much food as the original bottom. These same counts also showed that 4.53 times as much food was found in the riffle areas produced by the barriers as was found in these same areas before the installation of the improvements. Since these counts covered all the different bottom types and since the stream bottom in this section was composed of a rather uniform mixture of fine, medium, and coarse gravel and some rubble, the food production in this area before improvement was considered as unity. After improvement the 30.8% of riffle area produced 139.5% of the former total production, while the five per cent comprised of mucky area and plant beds produced 20% of the former total production; the 64.2% of the area which remained unchanged produced, of course, 64.2%. Thus, the total production of organisms in the improved section of the stream was increased to 223.7% of the former total production, and the improvements increased the food organisms in this section 123.7%.

In the second improved section, located below the upper dam, thirty-three structures were installed—twenty-one deflectors and twelve covers. The area of this section covered about 98,838 square feet. Before improvement the bottom in this section of the stream consisted of medium gravel, sand, and muck. The medium gravel covered 17,950 square feet which equalled 18% of the total area, the muck covered 5% of the total area (a maximum estimate) or 4,942 square feet, while the sand covered 77% or 76,046 square feet. The stream improvement devices in this section uncovered 7,740 square feet of gravel or 7.8% of the total area; produced 7,142 square feet of riffle area which equalled 7.2% of the total area; formed 18,455 square feet of mucky area equiva-

lent to 18.5% of the area; and produced 4,582 square feet of plant bed which equalled 4.6% of the total area. Thus, the barriers modified 38.1% of the total area. Using the results of the food determinations, it was calculated that the riffle areas formed by the barriers produced on the average 4.53 times as much food as the same area produced before improvement.

By using the results of the food determinations and the averages of the volume and number of organisms found on each type of bottom in the East Branch of the Black River, it was possible to calculate the food production in this section of the stream before and after improvement (Table 5). These calculations show that the volume of food was increased almost three times.

It is concluded that, since the improvement devices introduced into the Michigan streams studied have been found to be relatively stable and efficient in producing physical and biological changes, and since these changes have been found in test areas to increase the production of fish food organisms and probably of fish, the improvement work on Michigan trout streams has been successful. Nevertheless, additional evaluation studies on stream improvement, especially with reference to the effect on the abundance of fish, are still urgently needed.

TABLE 5. VOLUME OF FOOD PRODUCTION IN A SECTION OF THE EAST BRANCH OF THE BLACK RIVER BEFORE AND AFTER IMPROVEMENT, CALCULATED ON THE BASIS OF DETERMINATIONS OF BOTTOM ORGANISMS IN THE STREAM

Bottom Type	Average production in cubic centimeters on 4 square feet	BEFORE IMPROVEMENT		AFTER IMPROVEMENT	
		Area of each Bottom Type (square feet)	Total calculated production (cubic centimeters)	Area of each Bottom Type (square feet)	Total calculated production (cubic centimeters)
Sand	0.27	76,105	5,137	48,995	3,307
Muck	3.99	4,942	4,942	23,397	23,397
Gravel	2.76	17,791	12,276	14,719	10,156
Gravel Riffle	12.48	.....	.....	7,142	22,283
Plant Beds	5.32	.....	.....	4,585	6,098
Grand Total		98,838	22,355	98,838	65,241

AN EVALUATION OF THE METHODS AND RESULTS
OF STREAM IMPROVEMENT IN
THE SOUTHWEST

BY

CLARENCE M. TARZWELL

U. S. Forest Service

NORTH AMERICAN WILDLIFE CONFERENCE

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AN EVALUATION OF THE METHODS AND RESULTS OF STREAM IMPROVEMENT IN THE SOUTHWEST

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INTRODUCTION

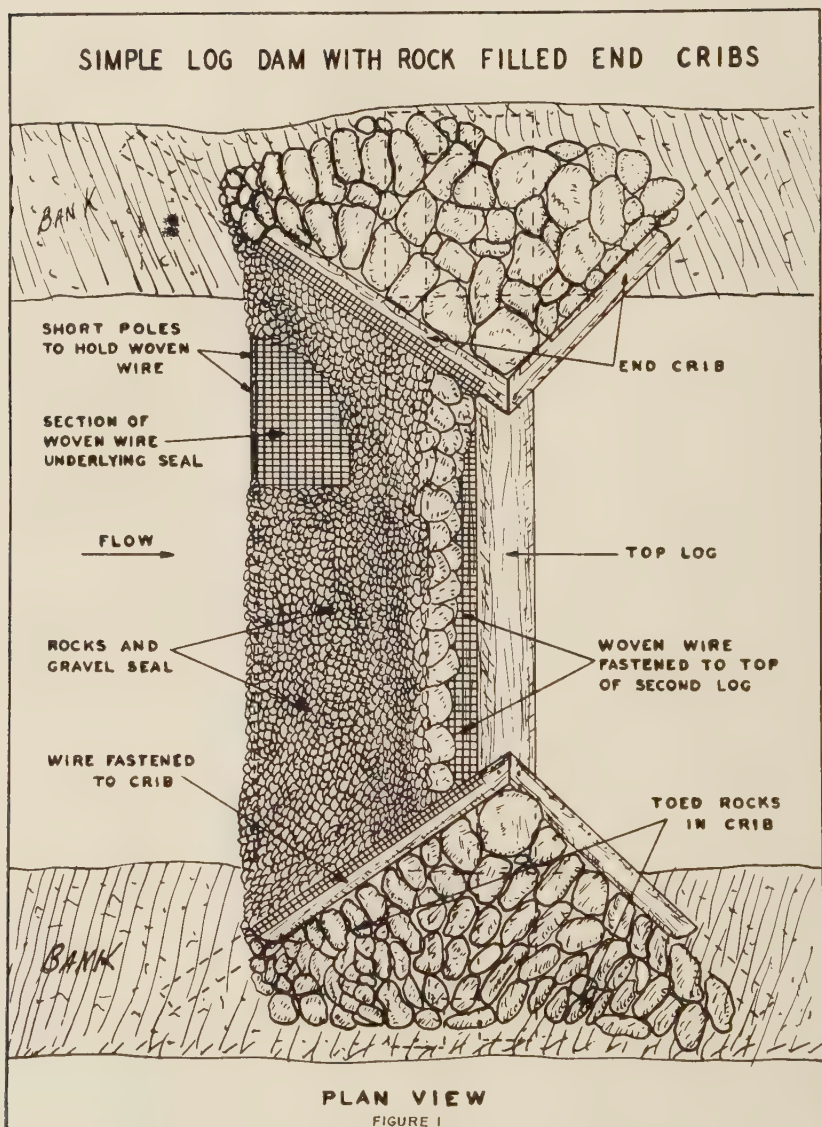
Trout stream improvement was undertaken on an extensive scale in the National Forests of Arizona and New Mexico by Region 3 of the U. S. Forest Service when federal emergency funds were made available for conservation work in 1933. Due to the emergency character of the work structures were placed in many streams during late 1933 and early 1934 without first making a survey of the waters. The need of surveys made previous to environmental improvement was recognized, however, and in 1934 stream and lake surveys and the planning of environmental improvements were carried on in several forests of Region 3 by the U. S. Bureau of Fisheries, in cooperation with the Forest Service. Due to lack of funds surveys were not conducted by the Bureau of Fisheries in 1935 but the improvement work was continued by the Forest Service under the general direction of experienced men. Later in 1935, Forest Service entered an agreement with the Bureau of Fisheries which provided for the Forest Service making lake and stream surveys in the Forests of Arizona and New Mexico. Since that time streams and lakes have been surveyed and studied before any environmental improvements were planned or constructed.

Since the beginning of the environmental improvement work in 1933 a total of 352 miles of stream improvement has been completed in the Forests of Arizona and New Mexico and many miles of stream bottom have been protected by being fenced and closed to grazing by domestic livestock. A total of 368 miles of trout stream has been surveyed and most of the improvement structures in the 352 miles of improved streams have been examined at least once. These examinations of the stream improvements which have been in operation for several years have shown the causes of failure of the structures, weak points and undesirable practices and have demonstrated the most effective and desirable devices and the best methods of stream improvement for Southwestern trout streams.

EVALUATION OF STREAM IMPROVEMENT DEVICES

Early in the environmental improvement work it became apparent that the methods developed in the east (Hubbs, Greeley and Tarzwell—1932) could not be applied directly to western streams. The

mountain streams of the West have a greater fall, their fluctuations of flow are usually greater and they present an entirely different improvement problem. The problems in Michigan generally consisted of the providing of pools and shelter, and the uncovering of the rubble gravel bottoms which are the chief food producing areas



(Tarzwell—1931). In the Southwest, however, the chief problems are the creation of pools and resting places and the slackening of the current so that it drops rather than sweeps away the debris and other organic materials so essential to food production in these streams. In view of these considerations it is clear why the dam is in general better suited for the improvement of southwestern streams than is the deflector. In these streams it is usually desirable to reduce the gradient and stabilize the bottom materials rather than to erode them. Dams accomplish this stabilization by stair-stepping the stream bottom through the formation of settling basins which collect and hold bottom materials moved by floods. This action usually destroys the pool created above the dam, thus the only permanent pool will be the one formed below the dam. If the dam is correctly built, that is, so built that the down stream edge projects some distance beyond the base, it will furnish cover as well as a permanent pool. Log dams built so that each log is slightly farther down stream than the one underneath it (Fig. 3) or board dams and dams having beneath their seal heavy woven wire or log sills covered with woven wire will provide cover for the pool they form on their downstream side.

It is essential to use some means for preventing the destruction of the seal of a dam due to the formation of a pool by the undercutting action of the water on the down stream side of the dam. Such destruction of the seal and the subsequent undermining of the dam can be prevented by the use of logs and heavy woven wire as shown in Fig. 3, or by the use of log sills covered with woven wire. This destruction of the seal has been the most common cause of the failure of dams in this Region.

When correctly placed and built, dams have withstood severe floods and have created fine pools. It has been found necessary, however, to embed the dams deeply into the banks, to brace them on the down stream side with knee braces and to protect the banks and ends of the dams against high water by means of stone filled end cribs or stone riprapping which extends from the down stream side up and over the ends of the dam and for some distance up the banks.

Of the various types of dams used in this Region, four have been chosen as the best. The simple log dam with rock filled end cribs (Fig. 1) has proven to be permanent and quite effective, especially when the logs are placed as shown in Fig. 3. When so built this dam not only forms a pool but also furnishes cover. This cover can be made more effective by placing a small secondary dam twenty to thirty feet below the main dam so as to back the water up beneath

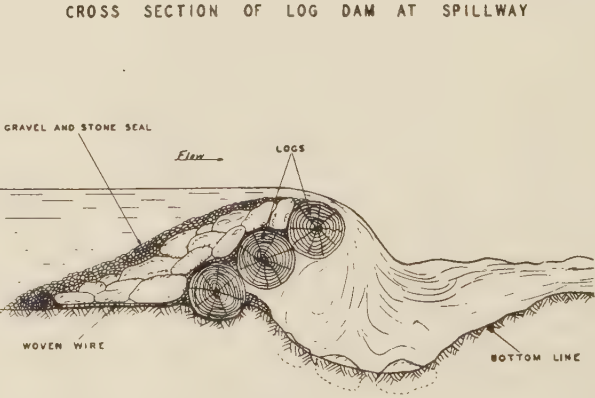
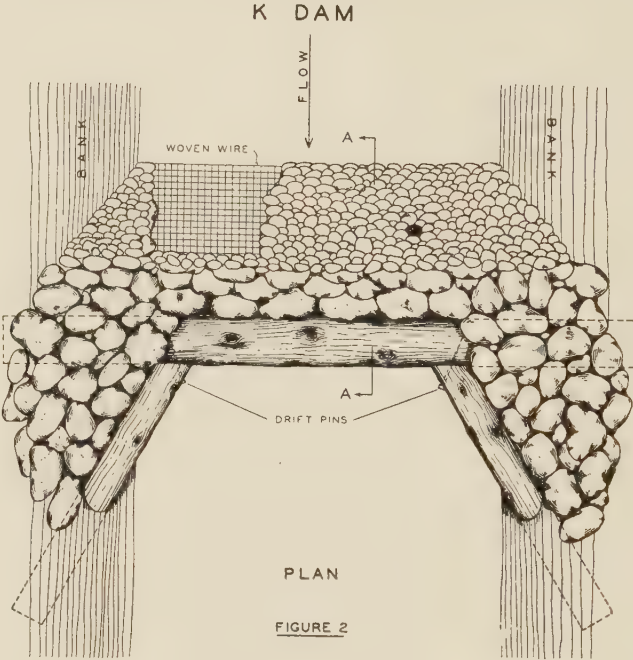


FIGURE 3

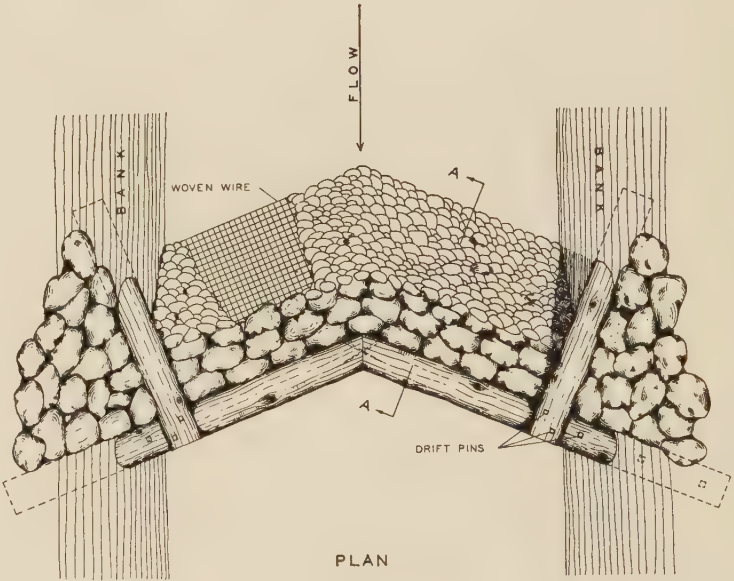
it. Where the banks are firm or floods are not severe, the end cribs can be omitted and a knee brace used as shown in Fig. 2. This type of dam is known as a K dam.

The wedge dam is quite effective and is especially suited to wide streams. While some feel that the wedge should point down stream in order to protect the banks, experience has shown that this is not necessary. If the banks are protected by a crib as shown in Fig. 4, very little erosion occurs. Also, when the wedge points up stream the dam functions better due to the action of the water and has less tendency to erode the banks than when it points down stream. When passing over an obstruction water tends to take a course perpendicular to the obstruction and thus in this instance is thrown to the center of the stream in passing over the dam and forms a better pool than when the wedge points down stream as in the latter type the flow is directed out toward the banks.

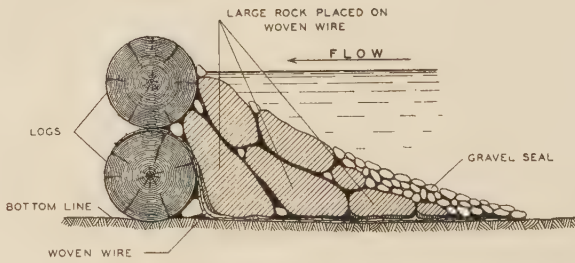
The plank or board dam has been found to be very effective and is constructed by placing a main log across the stream at the desired height and then laying planks of the desired length parallel to the flow with the up stream ends resting on the stream bottom and the down stream ends resting on the supporting log. This dam is a gravity type structure and since the planks rest on the bottom some distance up stream, undercutting and the formation of a pool on the down stream side does not destroy the seal but forms a pool under the planks which give excellent cover for trout. Knee braces on the down stream side of the supporting log and a sill under the up stream ends of the planks are desirable to give added strength to the dam. The seal is made by placing gravel and rocks on the planks.

While deflectors do not have a wide use there are certain situations in which they can be used to advantage, such as directing the current against a rocky cliff, narrowing the stream through confining the current and building up a bar below, or by forming pools in sections where there is no danger of bank erosion. Various types of deflectors have been used but the triangular crib deflector, Fig. 6, is considered the best.

The creation of suitable cover has proven to be a difficult problem in many southwestern streams. It is difficult to hold most covers in the streams and if submerged covers are used they usually lose their effectiveness by collecting silt, sand and gravel and forming islands. One of the most effective covers is the projecting submerged bank cover shown in Fig. 7. This cover may be rectangular or triangular in shape. It has been found that the rolling of large boulders into a stream, where they are readily available, is a very



PLAN
FIGURE 4



SECTION-AA
(LARGER SCALE)
FIGURE 5

WEDGE DAM

cheap and effective way of providing cover and small pools. This method of improvement has the advantage of being relatively permanent and it adds to rather than detracts from the natural beauty of the stream.

Another practice which adds to the natural beauty of a stream as well as improves the habitat for fish is the fencing of stream bottoms to exclude domestic stock. This practice has greatly improved many southwestern streams as the vegetation which has become established on the stream banks has prevented bank erosion, kept the streams narrow, provided shade and cover, and increased the supply of terrestrial food.

EVALUATION OF THE RESULTS OF STREAM IMPROVEMENT

Although a good deal of stream improvement work has been done in many sections of the country during the past four years, investi-

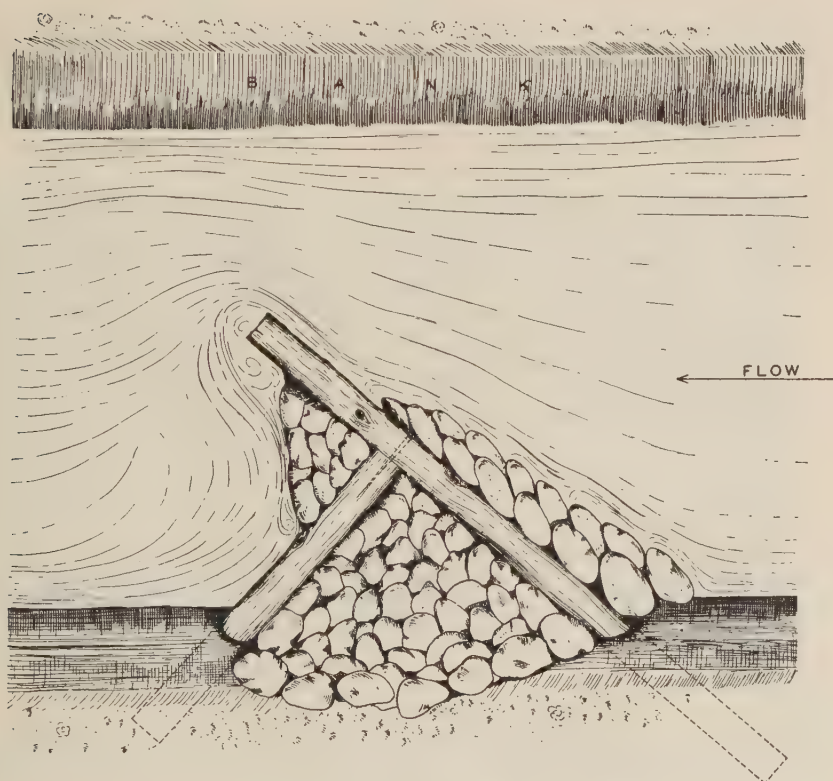
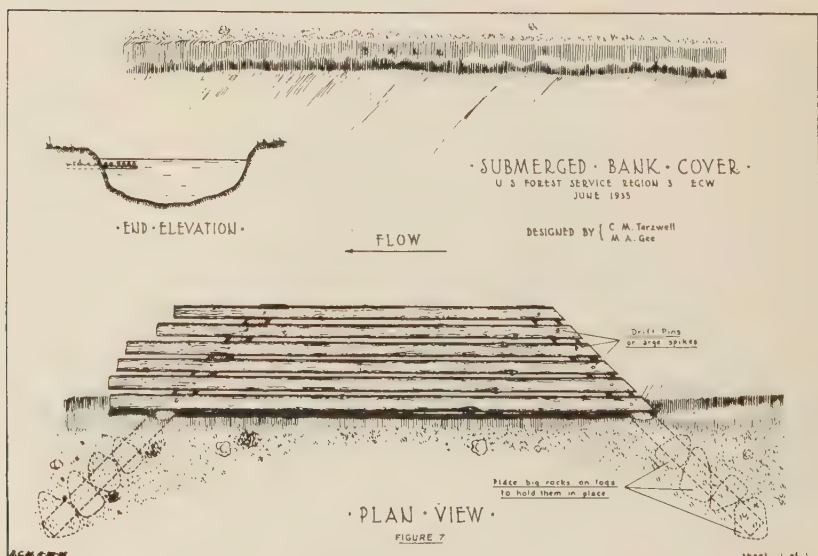


FIG. 6—PLAN, TRIANGULAR CRIB-WING DEFLECTOR

gations to determine the effects of the various types of improvements and to determine the value of the results of the improvement work have been largely neglected. Perhaps this is largely due to the fact, as pointed out by Eschmeyer (1936) that it is easier to install a so-called improvement than it is to determine whether or not it is beneficial. With the exception of the author's work in Michigan (Tarzwell, 1936) little evaluation work has been done and practically no results from investigations as to the value of stream improvement have as yet been published.

Due to the fact that environmental improvement was a new undertaking in the mountain streams of the Southwest, the Forest Service thought it advisable to carry on studies to determine the effects of stream improvement and to evaluate its results. Since the mountain streams of the Southwest are very different from Michigan streams it was clear that the results obtained there would not be applicable, in fact some believed that it would be impossible to increase the food supply in such streams (Davis, 1936). It was apparent that some knowledge of the value of stream improvement in mountain streams should be secured before the work was continued or expanded to any extent. Therefore, the Forest Service decided to make such investigations in conjunction with the stream surveys being conducted in the Region.*



*These surveys and investigations were conducted by Mr. M. A. Gee and the author, of the U. S. Forest Service.



FIG. 8—LOG DAMS—HORTON CREEK, ARIZONA

This photo shows the stone repping on the ends of the dams and the use of secondary dams to back the water up under the main dam.



FIG. 9—BANK COVER—HORTON CREEK, ARIZONA

The log bank cover shown in this photo has been covered with rocks and forest litter to give it a more natural appearance. Many persons never notice this is an artificial cover although the span under it is 6x15 feet and gives excellent cover for trout.

The most desirable method of determining the value of stream improvement work is to select a stream and determine the average food and fish yield and the rate of growth of the fish for a number of years and then to improve the stream, collect the same data after improvement and compare the results. This is a long time procedure and funds and time are not always available to carry it out. The next best procedure is to select two streams in the same locality which are as near identical as possible and improve one of them, using the other unimproved as a control to check the results of stream improvement in the other. This latter procedure is the one followed for the investigations here reported upon.

Horton Creek and Upper Tonto Creek on the Tonto National Forest in Arizona were the streams selected for these investigations which began in February, 1936. Horton Creek was improved by the CCC during 1933, 1934 and 1935, while Tonto Creek was left in its original condition. These streams are very similar as shown by survey and actual measurement and are believed to be well suited for testing the results of stream improvement. The measurements were made after Horton Creek was improved and they, therefore, show the area of Horton Creek after it had been increased by the large pools formed by the dams. The results of the stream measurements, which were taken accurately and thoroughly, are summarized in Table 1. A total of 1,050 individual width measurements were made on Upper Tonto Creek and 1,521 in Horton Creek. Depths were taken at intervals of one foot at each of these width measurements and the average depth computed.

TABLE 1

	Average Depth in inches		Average Width in feet		Length in Miles		Area in Acres	
	Horton	Tonto	Horton	Tonto	Horton	Tonto	Horton	Tonto
Rifle	7	11	12	13	2.39	2.87	3.72	4.83
Pool	17	19	15	13	1.14	.94	2.11	1.58
Totals					3.53	3.81	5.83	6.41

It will be noted from Table 1 that Upper Tonto Creek is 0.28 miles longer than Horton Creek and has 0.58 acres more water area. The greater pool area shown for Horton Creek is due to the improvements. Tonto Creek has a larger flow than Horton Creek but outside of these differences they are very similar, as both streams flow through the same type of rugged sandstone limestone country and are separated only by a narrow ridge projecting out from the Tonto Rim. Their valleys, soil conditions, shade and banks are similar and each stream is formed from springs which emerge from below the Tonto Rim at about the same elevation. Normally their

entire flow is spring water. The spring which forms Tonto Creek emerges at an elevation of 6,650 feet while the two springs that form Horton Creek emerge at an elevation of 6,850 feet. The two streams join at an elevation of 5,850 feet; therefore, Horton Creek falls 1,000 feet in 3.5 miles and Upper Tonto Creek falls 800 feet in 3.8 miles. The spring water which forms the creeks and the waters in the creeks at their junction are very similar as shown by chemical analysis (Table 2). Temperatures are also similar.

TABLE 2—ANALYSIS OF THE WATER IN HORTON AND TONTO CREEKS

				Tempera- ture (° F.)		Alkalinity				
		Date	Time	Air	Water	pH	Oxygen (ppm)	Carbon Dioxide (ppm)	MO (ppm)	Fnth.
Horton Spring	No. 1	8/15/37	4:15 PM	74	49	7.1	8.8	10	140	0
Horton Spring	No. 2	8/15/37	4:30 PM	74	50	6.8	8.3	13	98	0
Tonto Spring		8/16/37	11:30 AM	74	49	6.7	8.	18	99	0
Lower Horton		8/15/37	6:00 PM	78	70	8.3	7.	1	116	0
Lower Tonto		8/16/37	9:30 AM	78	58	7.7	8.4	1	111	0

While the temperature record for the lower portion of Tonto Creek is lower than that for lower Horton, it will be noted that the temperature of Tonto was taken in the morning when the water was cold while that in Horton was taken late in the day when water temperatures are at a maximum. This difference in temperatures is the reason for the difference in oxygen content.

The differences in the productivity of the improved stream, Horton Creek, and the unimproved stream, Tonto Creek, are being tested in three ways as follows: By an intensive creel census to determine the number, size and weight of the fish taken from each stream by fishermen; by quantitative studies of the bottom organisms on different bottom types in various portions of the two streams at periodic intervals through the year, and by the determination of the growth rate of the trout in the two streams by means of scale studies. These three methods of study will be discussed separately.

CREEL CENSUS

The value of a creel census in a fish management program was not widely recognized until just a few years ago. Many attempts have been made to secure a creel census by depending upon the fishermen to report the required data on devised forms but these attempts have resulted in partial returns of little or no value. To secure complete and reliable data qualified men must be employed to actually contact all fishermen and record the data. While the census work

on lakes has been quite intensive such work on streams has been very meager. A creel census was conducted on Dry River in New Hampshire by Smith (1936) and Lord (1935) conducted a creel census on Furnace Brook, Vermont, during the 1935 season through the co-operation of the fishermen. A very thorough and complete creel census was conducted on Big Spring Brook in West Virginia by Eugene Surber (1936) from 1933 through 1936. This census was especially valuable in that yield per acre was determined and correlated with planting records and growth rate.

Creel census studies for the purpose of determining the fish yield from an improved and unimproved stream were initiated on Horton and upper Tonto Creeks at the beginning of the 1936 fishing season and have been continued during the past two seasons. This work has been carried on as a CCC project and a man was stationed just below the junction of the two streams so he could contact the fishermen on their way to and from the streams. The census takers worked in two shifts and a man was present at the station during all the fishing hours every day of the week. As it was unlawful to fish after dark the men were kept on duty from 8:00 A.M. until 8:00 or 9:00 P.M., and it is believed that all fishermen were contacted. These streams are ideal for the taking of a creel census since a spur road runs up each canyon to a dead end, and one man stationed at the junction of the two streams can contact all the fishermen.

Special forms were devised for recording the catch of each fisherman. A copy of the form used is inserted below:

CREEL CENSUS RECORD

Stream _____	Forest _____				Date _____
Please record undersize fish and all failures to catch fish.					
Species Taken	No.	Legal Ave. Size	No.	Undersize Ave. Size	Lures Used (Check)
Rainbow Trout _____					Bait _____
Brown Trout _____					Spinner _____
Brook Trout _____					Dry Fly _____
Yellowstone Native _____					Wet Fly _____
Black spotted Native _____					Other _____
Hours fished: From _____		to _____		Weight of Catch _____	
Remarks: _____					
(Weather, water conditions, abundance of fish, etc.)					

The census taker was supplied with scales, rulers and other equipment necessary for securing the data required for the census blank and also scale sample envelopes and bottles with formalin for preserving stomachs. The fish were counted, measured and weighed by the census taker. Weights were taken in grams. The number of each species, their size, the time spent fishing, the species, number and average size of fish returned to the stream and the kinds of lures used were recorded by the census taker.

When a creel census is taken on streams which are stocked with fish it is necessary to know the rate of stocking for several years previous to the census in order to interpret the results. The stocking of trout in Horton and Upper Tonto Creeks during the past six years, as nearly as can be determined, is as follows:

Year	Horton Creek	Upper Tonto Creek
1932	0	0
1933	2,000 Rainbow Trout 3,800 Brook Trout	7,000 Rainbow Trout 1,750 Rainbow Trout
1934	0	500 Brown Trout
1935	0	500 Brown Trout
1936	3,000 Rainbow Trout 3,850 Yellowstone Native* and Brook Trout 50 Brown Trout	7,000 Yellowstone Native Trout 5,000 Rainbow Trout 6,000 Brook Trout 7,500 Yellowstone Native and Brook Trout
1937	1,375 Yellowstone Native Trout 5,575 Rainbow Trout 1,500 Brown Trout	6,850 Rainbow Trout 340 Yellowstone Native 3,750 Brown Trout
Totals	25,150	46,190

It will be noted that almost twice as many trout were placed in Tonto Creek as were placed in Horton Creek. All stocking was done by the Arizona Game and Fish Department and the above figures have been furnished through the courtesy of that department. Prior to 1937 most of the trout which were stocked in these two streams were fingerlings, but in 1937 some legal fish were planted. The legal size is 7 inches and the creel limit is 15 trout.

The results of the creel census on Horton and Upper Tonto Creeks for the past two years are summarized in Table 3. It will be noted that in spite of the fact that during the past six years Upper Tonto has received nearly twice as many trout as Horton Creek the total fish yield from Horton was greater each year of the census. The yield from Horton increased markedly over Tonto in 1937, as 624 more fish were removed from Horton that year than were removed from Tonto Creek. During the 1936 season the total catch from Tonto was 399 trout per mile, or 222 trout per acre, while from Horton it was 422 trout per mile, or 256 trout per acre. This is a very good yield from Horton Creek as no hatchery fish were placed in it during the two previous years, 1934 and 1935. The yield for the 1937 season was greater than that for 1936 and Tonto yielded 471 trout per mile, or 280 trout per acre, while Horton yielded 686 trout per mile, or 415 trout per acre. In 1936 the average number of trout taken per hour from Horton Creek was 1.61 trout, while from Tonto the average hourly catch was 1.39 trout. During the 1937 season the average hourly catch was the same in both streams,

*The Yellowstone Native Trout is *Salmo clarkii lewisi*.

namely 1.36 trout. This drop in the average catch per hour as well as the drop in the average size of the fish and the average catch per fisherman day is without doubt due to the great increase in the number of fishermen on the two streams. During the 1937 season there were nearly twice as many fishermen on the streams as there were during the 1936 season. The number of fishermen on Horton Creek increased from 260 to 546 and the total catch increased from 1,491 to 2,421, while on Tonto Creek the number of fishermen increased from 267 to 379 and the total catch from 1,422 to 1,797. The results of the creel census for the past two seasons show that the improved stream, Horton Creek, has yielded more trout.

There was a marked increase in the number of undersize trout hooked and returned to the streams in 1937. This may be due to heavier stocking, but the much larger number recorded for Horton Creek, more than twice the number recorded for Tonto, must mean that there are more young trout in Horton and that natural reproduction is more successful, as stocking has been much heavier in Tonto Creek. Rainbow trout have been observed to spawn on the gravel seals of the dams and it would appear that the stream improvements have increased natural reproduction as evidenced by the greater number of young trout.

It will be noted in Table 3 that the number of fishermen who failed to catch trout increased considerably in the 1937 season, especially on Horton Creek. During the 1936 season 15.35 per cent of the Tonto Creek fishermen failed to catch trout, while 24.8 per cent of the total number did not catch trout in 1937. On Horton Creek the percentage of failures was 13.46 in 1936 and 30.3 in 1937. These failures are largely due to the novices who were making their first attempt to catch trout. The larger number of failures recorded for Horton Creek are due to the fact most beginners and children were directed to that stream by the census taker during the early part of the season as fishing was better there and it was thought they would have a better chance to catch trout on that stream. The increased number of failures in 1937 is also due in part to the greater number of fishermen using the streams.

Experienced fishermen, especially the fly fishermen, made good catches and several limit catches were made. The average catch of those who caught fish is considered to be good as it was 6.3 trout for Tonto Creek and 6.37 trout for Horton Creek. These average catches compare favorably with the average catch of 7.2 trout recorded by Lord (1935) from his census on Furnace Brook, Vermont, and they exceed the average catch of 4.5 fish recorded by Eschmeyer (1935) in his Fife Lake, Michigan, census. The average fisherman

1936 AND 1937

Month	Number of Fisherman Days	Number Legal Fish Taken	Average Size in Inches	Average Catch of Fish	Fish per Hour	Failures to Catch Fish	Number Undersize Fish	Ratio Legal to Undersize
Stream	1936	1937	1936	1937	1936	1937	1936	1937
Tonto	40	72	8.4	7.4	1.76	7	3	1937 to 1
Horton	55	93	8.4	7.5	2.74	18	61	.92 to 1
Tonto	121	100	8.1	7.8	1.11	30	136	2.04 to 1
Horton	111	196	7.9	7.3	1.3	4	371	1.36 to 1
Tonto	50	87	8.2	7.7	1.54	14	284	1.86 to 1
Horton	50	148	8.1	7.4	1.05	9	121	1.77 to 1
Tonto	49	97	8.5	7.5	1.51	3	104	1.75 to 1
Horton	30	87	8.4	7.3	1.33	0	167	1.07 to 1
Tonto	7	23	8.4	8.4	1.35	0	81	2.94 to 1
Horton	14	23	8.6	7.4	1.45	0	21	1.66 to 1
Tonto	267	379	8.2	7.7	1.78	0	38	3.23 to 1
Horton	260	546	8.2	7.4	1.42	5	26	4.1 to 1
Tonto	1,422	1,797	5.33	4.74	1.36	41	721	1.61 to 1
Averages	1,491	2,421	5.72	4.43	1.36	35	631	.95 to 1

TABLE 4—SUMMARY OF CREEL CENSUS RETURNS BY SPECIES FROM HORTON AND TONTO CREEKS FOR THE SEASONS 1936 AND 1937

Stream	Rainbow Trout	Brook Trout	Brown Trout
	Number Legal	Number Legal	Number Legal
	Size Under	Size Under	Size Under
	Catch Total	Catch Total	Catch Total
	Percent	Percent	Percent
	Average Size in Inches	Average Size in Inches	Average Size in Inches
Tonto	1,121	8.3	8.7
Horton	1,215	8.2	8.9
Tonto	1,550	7.5	8.5
Horton	2,037	7.4	7.5
Yellowstone Native*	2,293	7.2	3.6
Tonto	42	19	39
Horton	36	17	31

*The Yellowstone Native Trout is *Salmo clarkii lewisi*.

day on Horton and Tonto Creeks during 1937 was 3.2 hours—slightly longer than the fisherman day recorded for Fife Lake. The records for 1937 show that the fly fishermen were more successful than the bait fishermen. The number of bait fishermen and fly fishermen, their average catch per hour, their number and percentage of failures, and the number and percentage of limit catches made by each are summarized in Table 5. The table shows that the majority of the limit catches were taken from Horton Creek.

TABLE 5—A COMPARISON OF THE EFFECTIVENESS OF FLY AND BAIT FISHING IN HORTON AND TONTO CREEKS DURING 1937

Stream	Lures	Number of Fishermen*	Average Catch	Fish per Hour	Failures to Catch Fish		Limit Catches	
					No.	Percent	No.	Percent
Horton	Bait	307	4.22 fish	1.33	94	30.61	12	3.91
	Fly	151	5.1 fish	1.76	36	23.84	13	8.61
Tonto	Bait	241	4.43 fish	1.28	66	27.39	10	4.15
	Fly	96	4.82 fish	1.55	17	17.71	4	4.17

*Fishermen using both bait and fly are not recorded.

On April 1 and 2, 1937, 1,250 marked trout were planted in Horton Creek and 800 were planted in Upper Tonto Creek.* These trout were marked by clipping the right pelvic fin and were the only trout of legal or near legal size planted until late in the season. These marked fish were placed in the streams to test the success of stocking in the improved and unimproved stream and also to gain some idea of the down stream migration of hatchery fish.

Since in some instances the fins were not clipped close enough, they began to grow again toward the end of the season so that marked fish could not readily be noted. For this reason all records of marked trout except those for May and June have been discarded and no definite conclusions can be drawn. The returns for May and June from Horton Creek show that the marked fish comprised 10 per cent of the total catch during May and 5.45 per cent of the June catch. The returns from Tonto Creek show that the marked fish comprised 5.5 per cent of the May catch and 6.41 per cent of the June catch. Marked fish were found 6 miles down stream on June 1, and many may have gone farther down stream into an inaccessible box canyon.

The number of each species of trout taken, their average size, and the percentage which they comprise of the total catch are summarized in Table 4. Rainbow trout were the dominant species taken in both streams. The brown trout averaged larger than the other trout. The Yellowstone Native or cutthroat trout (*Salmo clarkii lewisi*)

*These plants were made by the Arizona Game and Fish Department and the marking of the trout was carried on as a cooperative project by the Arizona Game & Fish Department and the Forest Service.

gave very poor returns considering the number planted. This trout appears to be even more migratory than the rainbow trout.

As has been shown previously the improved stream has yielded more trout than the unimproved stream even though the latter was stocked with almost twice as many trout. During 1937 the number of trout taken from Horton Creek exceeded the number from Tonto by over a third and the total production in pounds of trout was considerably greater. The weight of the fishermen's catches were secured by the census taker so that production per acre and total production for each stream could be determined. All fish were weighed in grams. The results of the weight records are summarized in Table 6.

TABLE 6—SUMMARY OF THE WEIGHTS OF TROUT REMOVED FROM HORTON AND UPPER TONTO CREEKS DURING 1936 AND 1937

Year	Stream	Total Catch	Average Weight in Grams	Pounds of Trout Removed	Yield in Pounds Per Acre	Meat Value Per Acre	Total Meat Value for Each Stream
1936	Tonto	1,422	94	293	45.6	\$27.36	\$175.80
	Horton	1,491	94	307	54.2	32.54	184.20
1937	Tonto	1,797	69	272.8	42.4	25.44	164.88
	Horton	2,421	63.7	339.3	59	35.40	203.58

The yields given in Table 6 furnish a good measure of the differences in productivity of the two streams. During the 1936 season the total catch of trout from Horton Creek exceeded that from Upper Tonto, the larger but unimproved stream, by 14 pounds, and in 1937 by 66.5 pounds. The yield in pounds per acre from Horton Creek was greater than that from Tonto Creek by 8.6 pounds in 1936 and by 16.6 pounds in 1937. This greater productivity of Horton Creek is believed to be largely due to stream improvement, since Tonto Creek was originally considered to be the better trout stream and it has been stocked much heavier.

As no figures are available for denoting the recreational value of trout fishing or the value to a community of having fishermen come into the area to fish the only definite economic return due to stream improvement which can be expressed is the value of the increased trout production in the form of meat. The values of the trout for meat for both streams and for each acre of water surface are given in Table 6.

Figuring the trout at their market value of \$0.60 a pound the meat values per acre of water surface in Horton Creek exceeded those of Upper Tonto Creek by \$5.16 in 1936 and by \$9.96 in 1937. The increased meat values in Horton Creek due to stream improvement can be found by multiplying the increased value per acre by the

number of surface acres in the stream. This increase in value amounted to \$30.08 in 1936 and to \$58.07 in 1937. These figures show that stream improvement in a mountain stream has produced tangible results both from the standpoint of increased production and economic returns.

It is certain that the value of trout for sport is many times their food value. Although it is impossible to determine the value to an individual or a group of individuals of the recreation, relaxation, fresh air, and exercise obtained while fishing, it is possible to make an estimate of the expenditures of a fisherman for a week-end fishing trip and to figure the value of the increased fishing due to stream improvement on the basis of such figures. When the cost of transportation, fishing tackle, liquid refreshments, field clothes and other incidentals are considered, it is apparent that very few fishermen can go fishing over the week-end in this Region for less than \$10.00. As he can go fishing twice on such a trip he will take on the average one and one-third pounds of trout according to the weight of the average catch taken from Horton and Tonto Creeks in 1937. His trout will, therefore, cost him \$7.50 a pound or 12.5 times the meat or food value of the trout. Using these figures to determine the worth of the increased fishing it is found that the stream improvements in Horton Creek increased the returns from that stream by \$406.00 in 1936 and \$784.00 in 1937. If these figures are at all correct, and it is felt that they are conservative, they indicate a justification for a sizable expenditure for stream improvement.

In addition to the value of the creel census on these streams for determining the difference in productivity of an improved and unimproved stream, this census is also of value in that it denotes the rate of trout production in mountain streams of the Southwest. The yields of 54.2 pounds and 59 pounds of trout per acre of water surface from Horton Creek and 45.6 pounds and 42.4 pounds per acre of water surface from Tonto Creek during the respective years of 1936 and 1937 are considered good production for small trout streams. This yield exceeds the production in Big Spring Creek, West Virginia, which was determined by Surber (1936) as varying between 27.7 and 34.8 pounds per acre over a four year period.

The actual average returns of \$32.54 and \$35.40 per acre of water surface from Horton Creek and of \$27.36 and \$25.44 per acre from Tonto Creek during 1936 and 1937, respectively, while representing only the food value of the trout removed, greatly exceed the generally estimated value placed on all phases of fishing.

When it is considered that during 1937 these two small streams, having a total length of 7-1/3 miles and a combined surface area

of 12.24 acres, yielded 612 pounds of trout having at the market price of \$0.60 a pound a food value of \$367.20, it is apparent that the worth of fish and fishing has been greatly underestimated. This is clearly demonstrated by the fact that in Senate Document No. 12, "Wild Life a Forest Resource and a Forest Wild Life Program," the average direct fish value of all the waters of Arizona was placed at \$0.44 an acre. If the recreational values of Horton and Tonto Creeks are considered in addition to and in proportion to the food values, the worth of these streams to the local community and to the people in general would be an astonishing figure.

QUANTITATIVE STUDIES OF BOTTOM ORGANISMS

Quantitative studies of the bottom food organisms for determining the standing crop in the improved stream, Horton Creek, and the unimproved stream, Tonto Creek, were begun in February, 1936. Square foot samples were taken from bed rock areas and from the various bottom types in the pools and riffles of the upper, middle and lower portions of both streams. These quantitative samples were taken at periodic intervals during the two year period that the study has been in progress. Samples have been taken every month of the year with the exceptions of November and January.

A bottom sampler similar to the one described by Surber (1936) was used in this work. This sampler was constructed so that when it was placed on the stream bottom its base enclosed an area of one square foot. After the net was securely in place the bottom materials were moved about to allow the current to sweep the organisms which were present back into the grit gauze bag which was attached to the down stream side of the sampler. If the organisms clung to the stones, each stone was held back in the bag and rubbed with the hands. If this failed to remove all the organisms the stones were placed in a bucket so the organisms could be removed later with forceps. When samples were taken from areas covered with aquatic moss or in pools having mucky deposits or debris all the plants or the materials on the pool bottom were swept back into the net. After all the organisms were secured from the area being sampled the materials which had collected in the net were washed by holding the net in the stream and shaking the material about. The material which remained in the net was placed in large white pans which contained water and the organisms were picked from the debris and preserved in 70 per cent alcohol. Later the organisms were separated into their various orders or groups, counted and their volume and wet weight determined. The volume of each order was determined by fluid displacement in a centrifuge tube

graduated to 0.1 c.c. Small volumes were measured in the bottom portion of the tube and their volume estimated to the nearest 0.01 c.c. The organisms were weighed on a beam balance having an accuracy of about .0105 grams and on an analytic balance to an accuracy of 0.001 gram.

The numbers, weights and volumes of the various samples taken from the same portions of the streams at different times throughout the two year period were averaged to obtain the average standing crop of bottom food organisms in the pools, riffles and bed rock areas of the upper, middle and lower sections of each stream and for the whole stream. These determinations have disclosed the relative productivity of the various bottom types and the pools and riffles. Mineral silt and bed rock bottoms are the poorest in food yield, but if aquatic moss occurs on the bed rock the yield from that type of bottom is usually quite large. Aquatic moss appears to have become more abundant on the bed rock areas of Horton Creek since improvement. It has been found that the riffles are richer than the natural pools but the artificial pools in Horton Creek are richer than the riffles due to the collection of debris and organic materials in them. It has also been found that in general a boulder rubble bottom is richer than a gravel bottom and coarse gravel has a larger standing crop of organisms than medium or fine gravel. These findings agree with those of Needham (1928 and 1929). The results of the quantitative bottom food studies on Horton and Tonto Creeks are summarized in Table 7.

TABLE 7*—AVERAGE STANDING CROP OF BOTTOM ORGANISMS IN THE POOLS, RIFFLES AND BED ROCK AREAS OF HORTON AND TONTO CREEKS DURING 1936 AND 1937

Bottom	Stream	Average Number Organisms Per Square Foot	Average Volume Per Square Foot in Cubic Centimeters	Average Weight Per Square Foot in Grams	Average Number Organisms Per Acre	Average Yield in Pounds Per Acre
Riffles	Horton	1,647	3.23	3.2	71,743,320	307
	Tonto	1,337	2.42	2.44	58,196,160	234
Pools	Horton	1,032	3.69	3.76	44,953,920	360
	Tonto	578	1.96	1.97	25,177,680	189
Bed Rock	Horton	697	.85	1.02	30,361,320	98
	Tonto	181	.32	.30	7,884,360	29

*Based on 116 bottom samples.

The quantitative studies of the bottom food organisms of Tonto and Horton Creek indicate that the latter has produced more food. The averages for the various bottom counts made over the two year period show that the standing crop of bottom organisms in Horton

Creek is greater than that of Tonto Creek by the following amounts: Riffles, 73 pounds per acre; Pools, 171 pounds per acre and bed rock, 39 pounds per acre. The total average standing crop of bottom organisms in Tonto Creek was found to be 1,407 pounds, and in Horton Creek 1,770 pounds, or a difference of 363 pounds in favor of the improved stream. The average production per acre from all the bottom types was 220 pounds for Tonto Creek and 304 pounds for Horton Creek, or a difference of 84 pounds per acre in favor of the improved stream. This is a definite and very appreciable difference in the food crop.

When the average total standing crop of bottom organisms in the two streams is compared with the average annual yield of trout during the past two years it is found that Tonto Creek yielded one pound of trout to 4.97 pounds of bottom organisms and in Horton Creek the ratio was one pound of trout to 5.48 pounds of bottom organisms. Trout are the only fish present in these streams. On the basis of this ratio the 363 pounds of bottom organisms which Horton Creek had in excess of that in Tonto Creek would represent 66 pounds of trout. Since the creel census shows that Horton Creek actually produced during the two year period an average of 40.3 pounds more trout than Tonto Creek it is evident that trout production is following rather closely the increased food production.

In order to understand how stream improvement has improved the food supply in Horton Creek it is necessary to analyze the changes produced by the improvement devices. A stream differs from a lake in many ways but one of the outstanding differences is that the stream water is continually in motion. The sources of fertilizing materials of a stream are not within the stream itself but such materials are constantly being brought into a stream and are just as constantly being swept away by the flow of water. It is, therefore, evident that only a very small part of the potential richness or basic food elements contained in or carried by the water of a swift stream are ever utilized. Bottom organisms and plants come in contact with a very small part of the total volume of the water. Since, as has been pointed out by Viosca (1935) various investigators have shown that the productivity of waters is dependent upon the sources of food supply which is in turn dependent upon the dead and living organic matter existing in or entering the water from outside sources, it is believed that some method which would remove a portion of these materials from the water and retain them in or on the stream bed would increase the basic productivity and the production of fish food and fish. The dams in Horton Creek have served this purpose by retaining much of the organic materials which formerly were

swept away by the current. The quiet pools above the dams have served as settling basins in which the current has dropped twigs, leaves, bark, duff and other organic materials. These materials have collected to a depth of several inches in many artificial pools and have produced a bottom material which yields several times the amount of bottom organisms produced on the original bed rock bottom as shown by quantitative bottom samples from these bottom types. Before Horton Creek was improved it had about one acre of bed rock bottom or ten times as much as Tonto Creek. The improvements have greatly reduced the bed rock area as the dams which were placed in it have formed large pools in which rich silt and debris have collected to form a bottom material high in food yield as pointed out above. The bed rock area has in this way been reduced to 0.37 acres and the productivity of the stream greatly increased as shown by the standing crop of 360 pounds per acre found to be present in these artificial pools.

As much of the duff and forest litter which finds its way into the stream is retained in the artificial pools rather than being swept away, it has an opportunity to decay and thus adds fertilizing elements slowly and steadily to the stream. It may be this decay of large amounts of organic materials in the pools is responsible for the greater yield of the Horton Creek riffles.

When the quantitative bottom samples for Horton and Tonto Creeks were analyzed the number of individuals in each order of insects or the other phyla present in the sample and their volumes were determined. These tabulations for the samples taken in the pools, riffles and bed rock areas of each stream have been summed up so that the groups or forms having the greatest volumes and largest numbers of individuals could be determined and any qualitative and quantitative changes in the bottom fauna of the improved stream noted. The results of these tabulations are summarized in Table 8. These summations show that the insects are dominant among the stream bottom organisms both in numbers and volume as they constitute almost 100 per cent of the total volume or organisms from bed rock areas, over 98 per cent of the volume from riffles and over 90 per cent of the volume from the pools. Among the forms other than insects the Mollusca are the most important, especially in the pools. With the exception of the artificial pools in Horton Creek the Trichoptera, Diptera, Ephemeroptera and Coleoptera are the dominant forms in point of numbers and make up the greater part of the total number of organisms found in the bottom samples. With the exception of the Odonata and certain other exceptions in the improved stream, these four orders of insects also make up the greater

part of the volume of the stream bottom organisms. Although the Odonata constitute a very small part of the total number of organisms occurring in the riffles, they constitute a considerable portion of the total volume found there, especially in the improved stream where they form 19.22 per cent of the total volume and rank third in volume. The same is true for the Plecoptera in the riffles of the improved stream as they represent a very small part of the total number of organisms but rank fifth in volume. The opposite is true for the Mollusca in the artificial pools as although they are dominant in numbers they form but a relatively small portion of the total volume. In view of these facts it is apparent that in designating the relative importance of the various orders of insects in bottom food samples the order of importance should be based on volumes or on both volumes and numbers. One large dragon fly larva often has a volume equivalent to several hundred Coleoptera or Mayfly larvae and it may represent a volume equal to several hundred to 2,000 chironomid larvae as evidenced by actual measurements from Horton Creek.

Certain differences in the bottom organisms of the improved and unimproved stream are indicated in Table 8. Mollusca, chiefly small clams, occur in much greater numbers in the artificial pools. It appears that these quiet pools with their rich organic bottoms are favorable for these small clams. As many as 5,000 have been found in an area of one square foot of such pool bottoms. Ostracods often occur in great numbers in the artificial pools but cannot always be successfully separated from the debris and counted. In the bed rock areas of the improved stream the Trichoptera are dominant in numbers and volume while in the unimproved stream the Ephemeroptera are dominant in numbers and volume.

GROWTH RATE STUDIES

Scale studies have been carried on* during the past two years to determine the age and average growth rate of the trout in the improved and unimproved stream. The length of the trout at the end of each growing season was calculated from the scale measurements and the length of the trout at the time of capture. (These trout were measured to the nearest 0.1 cm. and weighed to the nearest 0.1 gm.) The annual growth rates obtained in this way were averaged to obtain the average annual growth for each year of life of the trout from each stream and for Horton Creek before and after improvement. (Ages and growth rates were determined for 220 trout.

*Mr. M. A. Gee has carried on the scale studies and calculated the length of the trout at the end of each growing season.

Insofar as possible all hatchery fish were discarded.) The results of these determinations are summarized in Table 9:

TABLE 9—AVERAGE ANNUAL GROWTH RATES OF TROUT IN TONTO CREEK AND IN HORTON CREEK BEFORE AND AFTER IMPROVEMENT

	Tonto Creek	Horton Creek	
		Before Im- provement	After Im- provement
Average growth during first year of life	2.9 inches	2.6 inches	3.1 inches
Average growth during second year of life	2.4 inches	2.6 inches	2.6 inches
Average growth during third year of life	2.2 inches		2.5 inches
Average growth during fourth year of life	2.2 inches		2.3 inches
Average length at end of fourth year	9.7 inches		10.5 inches

Since improvement the trout in Horton Creek have grown faster during each year of their life than those in Tonto Creek. Although this difference is not great it would amount to 0.8 inch for each trout at the end of the fourth growing season, as indicated in Table 9. Although this does not seem much when only one trout is considered it means a good deal on several hundred trout and represents many pounds of food. As shown in Table 9 the average annual growth of the trout in Horton Creek during the first year of life has increased a half inch since improvement, while growth during the second year of life has remained the same. This indicates that before improvement the trout in Horton Creek at the end of the second year of growth averaged 5.2 inches long, but since improvement have averaged 5.7 inches long.

Although Horton Creek was improved during 1933, 1934 and 1935 practically all the improvements were constructed during 1934. Therefore, 1935 is the first year in which the results of improvement should be manifested. A comparison of the average annual growth rate of all age classes of trout in the improved and unimproved stream before and after 1935 is given in Table 10:

TABLE 10—AVERAGE YEARLY GROWTH RATES FOR ALL AGE CLASSES OF TROUT IN HORTON AND TONTO CREEKS BEFORE AND AFTER IMPROVEMENT

Year	Tonto	Horton	Difference
1934	2.7 inches	2.6 inches	—0.1 inches
1935	2.5 inches	2.7 inches	+0.2 inches
1936	2.5 inches	2.6 inches	+0.1 inches

A comparison of these growth rates shows that during 1934 before Horton Creek was improved to any extent the average annual growth rate was greater in Tonto than it was in Horton, while since improvement the average annual growth rate has been greater in Horton Creek by 0.2 inch in 1935 and 0.1 inch in 1936. As these studies have been carried on for only a short time and since the differences are small they may not have any significance. If these differences are not due to chance but are real, they indicate that during the two years since improvement the trout in Horton Creek have grown

0.3 inch more than those in Tonto Creek. Although this doesn't mean much when one fish is considered it represents a total increase in length of 726 inches or over 60 feet of increased growth on the 2,421 trout taken from Horton Creek last year.

CONCLUSIONS

The investigations which have been conducted by the Forest Service in the National Forests of Arizona and New Mexico have shown that dams are the best improvement devices for many southwestern streams and when they are correctly located and constructed are relatively permanent and effective.

The special investigations being conducted on Horton and Tonto Creeks in the Tonto National Forest in Arizona have demonstrated that to date the improved stream, Horton Creek, has yielded a greater number of trout and more pounds of trout per acre than Tonto Creek. Also that the standing crop of bottom organisms is much greater in the improved stream being on the average 84 pounds more per acre and that the trout have grown slightly faster in the improved streams.

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